LEPTONIC DECAYS OF CHARM AND BEAUTY MESONS

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Recent measurements of purely leptonic D_s- and D-meson decays from BES, E653 and L3 experiments are presented. The average value of the decay constant f_{D_s} of 263 ± 22 MeV is derived using the combination of these new measurements with those previously reported. The results of the searches for purely leptonic B-meson decays done at LEP by ALEPH and L3 Collaborations are also reviewed along with the discussion of the constraints on SUSY parameters arising from the negative results of these searches.

1 Introduction

Purely leptonic decays of heavy mesons are of particular interest due to their sensitivity to meson decay constants, which connect the absolute rate of various heavy-flavour transitions (e.g. $B\bar{B}$ oscillations and some hadronic decays) to CKM matrix elements. There exist several theoretical predictions for f_D, f_{D_s} and f_B decay constants [1]; the agreement between the different theoretical approaches, however, is not very good. Therefore, the measurement of the Cabibbo-favoured process[a] $D_s^- \to \ell^- \bar{\nu}_\ell$, the easiest to access experimentally, can help discriminate among different theoretical models. In the framework of the Standard Model the decay width of this process is predicted to be

$$\Gamma = \frac{G_F^2\, f_{D_s}^2\, |V_{cs}|^2\, M_\ell^2\, M_{D_s}}{8\pi}\,(1-\frac{M_\ell^2}{M_{D_s}^2})^2 \qquad (1)$$

where G_F is the Fermi coupling constant, M_{D_s} and M_ℓ are the masses, f_{D_s} is the decay constant and V_{cs} is the CKM mixing matrix element. Measurements of the leptonic decays $D_s^- \to \mu^- \bar{\nu}_\mu$ have already been reported by WA75 and CLEO experiments[2,3]. However the significance of the measurement of $D_s^- \to \tau^- \bar{\nu}_\tau$ decays, based on the observation of two events[4], suffers from large statistical and systematic errors.

Within the Standard Model, the branching fraction $\mathcal{B}(B^- \to \tau^- \bar{\nu}_\tau)$ is expected to be $\simeq 0.5 \times 10^{-4}$ for $f_B = 190$ MeV and $|V_{ub}| = 0.003$. A measurement of such a small branching fraction is not very likely in the near future, given the limited size of the available data samples of B-mesons. Nevertheless, in the models with two Higgs doublets, it can be significantly larger due to the contribution of the charged Higgs Boson [5]. The enhancement factor depends on the model parameters, in particular on $\tan\beta$ and $M_{H^\pm}$. No evidence for such enhancement has been reported by the experiments [6,7] so far.

In this article the recent measurements of purely leptonic D_s- and D-meson decays from BES, E653 and L3 experiments[8,9,10] are presented and the average value for the decay constant f_{D_s} is derived. The results of the searches for purely leptonic B-meson decays done at LEP by the ALEPH and L3 Collaborations [8,11] are also reviewed.

[a] The charge conjugate decays are implied here and throughout this paper.

2 Leptonic decays of charm mesons

The analysis of the $D_s^- \to \tau^- \bar{\nu}_\tau$ decays is done by the L3 experiment [8] using the decay chain $Z \to c\bar{c}$, $c \to D_s^{*-} \to \gamma D_s^-$, $D_s^- \to \tau^- \bar{\nu}_\tau$ followed by $\tau^- \to l^- \bar{\nu}_l \nu_\tau$, for which the signature is a combination of lepton, photon and missing energy in one of the event hemispheres. The energy and direction of the D_s^- is reconstructed from all the other particles, excluding this lepton, using energy-momentum conservation:

$$\vec{P}_{D_s^-} = -\sum_{i\neq \text{lepton}} \vec{p}_i \qquad (2)$$

$$E_{D_s^-} = \sqrt{s} - \sum_{i\neq \text{lepton}} E_i \qquad (3)$$

The energies of all reconstructed particles (E_i^{fit}) are then varied in the kinematic fit to minimise their deviations from the experimentally measured values

$$\chi^2 = \sum_{i\neq \text{lepton}} \frac{(E_i^{fit} - E_i)^2}{\sigma_{E_i}^2}, \qquad (4)$$

under the constraint $E_{D_s^-}^2 - \vec{P}_{D_s^-}^2 = M_{D_s^-}^2$. This

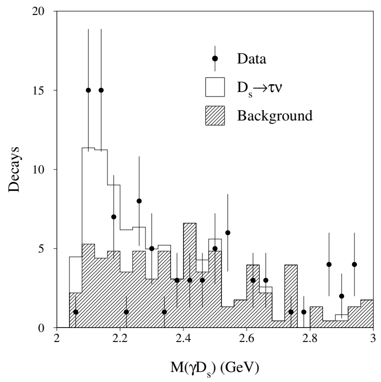

Figure 1: $M(\gamma D_s^-)$ invariant mass distribution for the selected events. The hatched histogram represents the background, the open histogram shows the signal contribution.

procedure yields an energy resolution for D_s^- mesons of $\sigma(E_{D_s^-}) \sim 3.0$GeV, and the angular resolution of 60 mrad. This precision is sufficient to see a peak ($\sigma \sim 52$ MeV/c^2) in the γD_s^- invariant mass spectrum for the decay chain $D_s^{*-} \to \gamma D_s^-$, $D_s^- \to \tau^- \overline{\nu}_\tau$ (Fig. 1) A binned maximum-likelihood fit, which accounts for a small admixture from $D_s^- \to \mu^- \overline{\nu}_\mu$ and $D^- \to \ell \overline{\nu}_\ell$ decays, yields

$$\mathcal{B}(D_s^- \to \tau^- \overline{\nu}_\tau) = (8.0 \pm 3.0 \pm 1.8 \pm 1.9)\% \quad (5)$$

where the first error is due to data and Monte Carlo statistics, the second one includes experimental uncertainties and the third one accounts for normalisation uncertainties.

The analysis of $D_s^- \to \mu^- \overline{\nu}_\mu$ decays performed by the E653 experiment [9] in Fermilab is

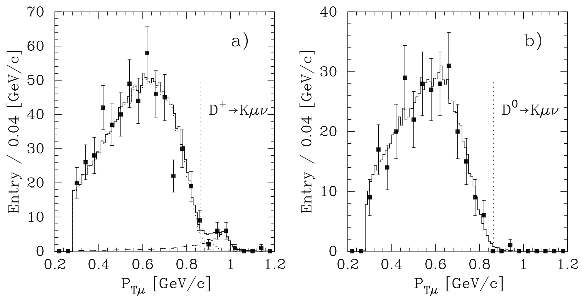

Figure 2: $P_{T\mu}$ spectra for a) muonic one prong events and b) muonic two prong decays. The experimental data (dots with error bars) are compared with the Monte Carlo predictions (solid histograms). The dashed line represents contribution from $D_s^- \to \mu^- \overline{\nu}_\mu$ decays. The vertical dotted line indicates the $P_{T\mu}$ limit for the main semileptonic modes.

very similar to the one reported earlier by the WA75 experiment [2]. This is a fixed target experiment with an emulsion target and muon trigger. The charm particles are produced in the interactions of a 600 GeV/c π^- beam in the emulsion. Their production and decay vertices and line of flight are measured directly by scanning the emulsion. The distribution of $P_{T\mu}$, the momentum of the muon transverse to the line of flight of the charmed hadron, is shown in Figure 2a for $D^\pm$-meson muonic one prong decays candidates. Figure 2b shows the corresponding distribution for D^0-meson muonic two prong decays candidates. The kinematic limit on $P_{T\mu}$ is 0.865 GeV/c for the main semileptonic D-meson decays. Clear excess above this kinematic threshold is observed in the charged topology due to the presence of $D_s^- \to \mu^- \overline{\nu}_\mu$ decays and no excess is observed above the threshold in the neutral topology. The corresponding branching fraction is

$$\mathcal{B}(D_s^- \to \mu^- \overline{\nu}_\mu) = (0.30 \pm 0.12 \pm 0.06 \pm 0.05)\% \quad (6)$$

where the first error is statistical, the second one includes experimental uncertainties and the third one includes normalisation uncertainties due to the error on $\mathcal{B}(D_s^- \to \phi \mu^- \overline{\nu}_\mu)$ from PDG [12].

Table 1: Summary of f_{D_s} measurements from the leptonic decays of D_s^- mesons.

Experiment	f_{D_s} (MeV)
WA75 (μ)	$223 \pm 45 \pm 20 \pm 47$
CLEO (μ)	$288 \pm 30 \pm 30 \pm 36$
BES ($\mu + \tau$)	$430\ ^{+150}_{-130} \pm 40$
E653 (μ)	$195 \pm 36 \pm 20 \pm 26$
L3 (τ)	$321 \pm 60 \pm 36 \pm 38$
χ^2/N_{dof}	5.8 / 4
Probability	21%
Average	263 ± 22

The summary of all existent measurements of f_{D_s} decay constant is presented in Table 1. The original results from WA75 [2], CLEO [3] and E653 [9] were corrected for the subsequent changes [13] in the measured values of $\mathcal{B}(D_s^- \to K^+K^-\pi^-)$ and $\mathcal{B}(D^0 \to \mu\nu_\mu X)$, $\mathcal{B}(D_s^- \to \phi\pi^-)$, and $\mathcal{B}(D_s^- \to \phi \ell \nu_\ell)$. The average of all the measurements, normalised to $\mathcal{B}(D_s^- \to \mu^- \overline{\nu}_\mu)$, is derived assuming Poisson statistics for the number of observed events in the individual experiments. The systematic errors are assumed to be uncorrelated. All

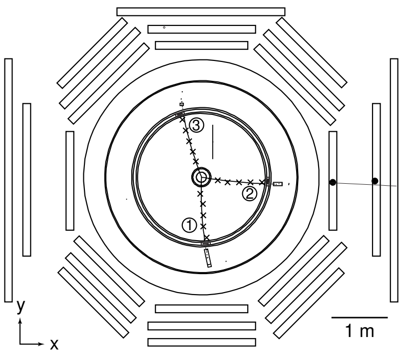

Figure 3: The event display for the $D^- \to \mu^-\bar{\nu}_\mu$ candidate. Track 2 is the μ^-, and tracks 1 and 3 are K^- and π^+ from D^0 decay respectively.

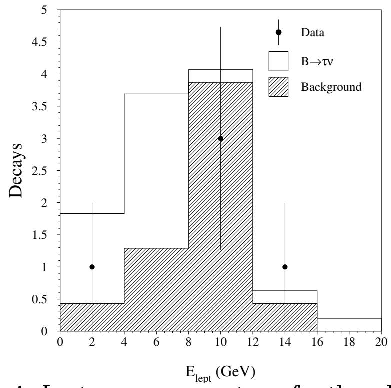

Figure 4: Lepton energy spectrum for the selected $B^- \to \tau^-\overline{\nu}_\tau$, $\tau^- \to l^-\overline{\nu}_l\nu_\tau$ candidates. The hatched histograms represents the background, the open histogram shows the signal contribution assuming $\mathcal{B}(B^- \to \tau^-\overline{\nu}_\tau) = 10^{-3}$.

these measurements are in a good agreement, with an average $\mathcal{B}(D_s^- \to \mu^-\overline{\nu}_\mu) = (0.547 \pm 0.076)\%$ and $\chi^2/\text{dof} = 5.8/4$. The probability to have a χ^2 equal or worse than that due to statistical fluctuations is 21%. The error on $\mathcal{B}(D_s^- \to \mu^-\overline{\nu}_\mu)$ is multiplied by factor $\sqrt{5.8/4}$ using PDG prescription [13] when extracting the f_{D_s} value.

Purely leptonic decays of D^- mesons have been studied by the BES Collaboration using reaction $e^+e^- \to D^{*+}D^-$ at centre of mass energy 4.03 GeV [10]. This final state is characterised by D^+ mesons in the momentum range 370-650 MeV/c or by D^0 mesons in the range 465-550 MeV/c. These ranges are inaccessible to D mesons from $D^*\bar{D}^*$ and $D\bar{D}$ final states. Requiring fully reconstructed D^+ or D^0 mesons, one candidate $D^- \to \mu^-\bar{\nu}_\mu$ decay recoiling against the reconstructed $D^0 \to K^-\pi^+$ decay (Fig. 3) is found in the data. The expected background in this mode is estimated to be 0.03 events. From this observation the value of the decay constant is calculated to be

$$f_D = 300\ ^{+180}_{-150}(\text{stat})\ ^{+80}_{-40}(\text{syst})\ \text{MeV}$$

As there is one observed event and non-zero background expectations, this result requires further confirmation. It does not contradict an upper limit $\mathcal{B}(D^- \to \mu^-\bar{\nu}_\mu) < 0.07\%$ set by MARK III experiment at 90% CL [14].

3 Search for leptonic decays of B-mesons

A search for the decay chain $b \to B^- \to \tau^-\overline{\nu}_\tau$, $\tau^- \to X\nu_\tau$ has been performed by the L3 experiment [8]. The signal consists of a track not pointing to the primary interaction point, large missing energy and low particle multiplicity in one of the event hemispheres. The track, not pointing to the primary vertex, is identified either as a lepton or a hadron and is assumed to be τ decay product. The energy spectrum of selected leptons is presented in Figure 4. The background shape is mostly due to the selection cuts, which require a very energetic B^- and little hadronic activity and thus lead to preferential selection of high energy leptons from the semileptonic decays. The selection efficiency for genuine $B^- \to \tau^-\overline{\nu}_\tau$ decays is reasonably flat in the energy range from 1 to 10 GeV. Hadronic tau decays require further discrimination from the semileptonic background, which at this point consists mostly of decays with low energy leptons (<1GeV) and high energy neutrino. The energy and invariant mass of all the particles, except the charged tau decay product, in the 0.5 rad half-angle cone around the reconstructed B^- direction are used to further discriminate the background (Fig. 5). The final data distributions agree well with the background expectations both for the leptonic and hadron channels and show no evidence for the signal. The likelihood function used to calculate the upper limit on $\mathcal{B}(B^- \to \tau^-\overline{\nu}_\tau)$ decays is based on the data distributions presented in Fig. 4 and Fig. 5b. The limit is calculated to be

$$\mathcal{B}(B^- \to \tau^-\overline{\nu}_\tau) < 5.6 \times 10^{-4} \text{ at 90\% CL} \quad (7)$$

The ALEPH Collaboration prepared an update [11] of their previously published analysis [7].

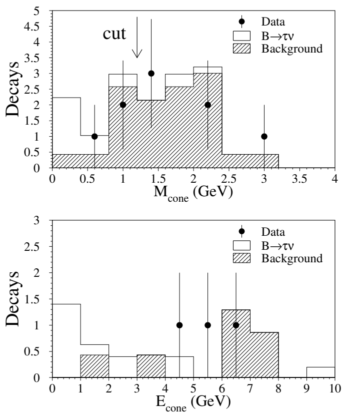

Figure 5: Selected candidates for the decay chain $B^- \rightarrow \tau^-\overline{\nu}_\tau$, $\tau^- \rightarrow \nu X_{\mathrm{hadr}}$. The distributions of the invariant mass (a) and total energy (b) for all particles, but identified charged tau decay product, in the 0.5 rad half-angle cone around the reconstructed B^- direction. The hatched histogram represents the background, the open histogram shows the signal contribution assuming $\mathcal{B}(B^- \rightarrow \tau^-\overline{\nu}_\tau) = 10^{-3}$. Fig. 5b shows only events satisfying the cut indicated on the Fig. 5a.

The analysis technique is based on selecting events with large missing energy and no leptons in one of the event hemispheres, and on b-tagging of the opposite hemisphere. Two candidate events are observed in the date for $E_{\mathrm{miss}} > 35$ GeV consistent with the background expectations of 7.1 ± 4.2 events. The conservative limit (without background subtraction) is derived to be

$$\mathcal{B}(B^- \rightarrow \tau^-\overline{\nu}_\tau) < 1.6 \times 10^{-3} \ \text{ at } 90\% \text{ CL}$$

Assuming $f_B = 190$ MeV and using $V_{ub} = 0.0033 \pm 0.0008$ [15] the following constraint is obtained from L3 limit on $\mathcal{B}(B^- \rightarrow \tau^-\overline{\nu}_\tau)$:

$$\frac{\tan\beta}{M_{H\pm}} < 0.38 \ \text{ at } 90\% \text{ CL}$$

It approaches the best limits on $\tan\beta$ and $M_{H\pm}$ from the proton stability [16] and measurements of the $b \rightarrow s\gamma$ transition [17]. It will become complimentary to these limits with the increase of sensitivity to $B^- \rightarrow \tau^-\overline{\nu}_\tau$ and more reliable predictions for the decay constant f_B.

4 Conclusions

The experimental accuracy of determination of the decay constant f_{D_s} has become comparable to the best theoretical predictions. The accuracy will be further improved with more results from CLEO and LEP experiments. Given that, improvements in the precision of theoretical predictions for f_{D_s} and better quantitative understanding of the relations between f_{D_s} and f_B is vitally needed.

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References

1. J.Richman and P.Burchat, *Rev.Mod.Phys.* **67**, 893 (1995).
2. S.Aoki *et al.*, WA75 Collaboration, *Prog.Theor.Phys.* **89**, 131 (1993).
3. D.Acosta *et al.*, CLEO Collaboration, *Phys.Rev.* D **67**, 5690 (1994); D.Gibaut *et al.*, CLEO note CONF 95-22, June 1995.
4. J.Z.Bai *et al.*, BES Collaboration, *Phys.Rev.Lett.* **74**, 4599 (1995).
5. W.S.Hou, *Phys.Rev.* D **48**, 2342 (1993).
6. M.Artuso *et al.*, CLEO Collaboration, preprint CLNS 95/1331, March 31, 1995.
7. D. Buskulic *et al.*, ALEPH Collaboration, *Phys.Lett.* B **343**, 444 (1995).
8. T.Anticic, A.Kunin and P.Pakhlov, L3 Note 1988, September 1996.
9. K.Kodama *et al.*, E653 Collaboration, preprint DPNU-96-33, June 1996
10. J.Z.Bai *et al.*, BES Collaboration, preprint SLAC-PUB-7147, April 1996.
11. ALEPH Collaboration, contribution to this Conference, ICHEP-96, PA10-019.
12. L.Montanet *et al.*, Particle Data Group, *Phys.Rev.* D **50**, 1173 (1994).
13. R.M.Barnett *et al.*, Particle Data Group, *Phys.Rev.* D **54**, 1 (1996).
14. J.Adler *et al.*, MARK3 Collaboration, *Phys.Rev.Lett.* **60**, 1375 (1988).
15. J.Alexander *et al.*, CLEO Collaboration, contribution to this Conference, ICHEP-96, PA05-081.
16. J. Hisano, H. Murayama and T. Yanagida, *Nucl.Phys.* B **402**, 46 (1993).
17. M.S.Alam *et al.*, CLEO Collaboration, *Phys.Rev.Lett.* **74**, 2885 (1995).