PROCEEDINGS

Experimental Status of Leptonic $\mathrm{D_s}$ Decays

Stefan Söldner-Rembold* †
CERN, CH-1211 Geneva 23, Switzerland.
E-mail: `stefan.soldner-rembold@cern.ch`

ABSTRACT: The measurements of the leptonic branching ratios $\mathrm{BR}(\mathrm{D_s} \rightarrow \tau\nu)$ and $\mathrm{BR}(\mathrm{D_s} \rightarrow \mu\nu)$ are reviewed. The values of the $\mathrm{D_s}$ decay constant $\mathrm{f_{D_s}}$ derived from the measurements are updated and a world average is calculated taking into account the large correlations between the measurements.

1. Introduction

The branching ratio of the purely leptonic $\mathrm{D_s} \rightarrow \ell^- \bar{\nu}_\ell$ decay[1] can be calculated [1] using

$$\mathrm{BR}(\mathrm{D_s} \rightarrow \ell^- \bar{\nu}_\ell) = \frac{G_\mathrm{F}^2}{8\pi} m_{\mathrm{D_s}} m_\ell^2 \left(1 - \frac{m_\ell^2}{m_{\mathrm{D_s}}^2}\right)^2 |V_\mathrm{cs}|^2 \tau_{\mathrm{D_s}} \mathrm{f}_{\mathrm{D_s}}^2, \quad (1.1)$$

where $m_{\mathrm{D_s}}$ is the mass and $\tau_{\mathrm{D_s}}$ the lifetime of the $\mathrm{D_s}$ meson, $\mathrm{f_{D_s}}$ the $\mathrm{D_s}$ decay constant and V_cs the corresponding CKM matrix element. G_F denotes the Fermi coupling constant and m_ℓ the mass of the lepton.

Several models for the calculation of the decay constant $\mathrm{f_{D_s}}$ exist: potential models predict $\mathrm{f_{D_s}}$ in the range from 129 MeV to 356 MeV [1], QCD sum rule models predict $\mathrm{f_{D_s}} = 235 \pm 24$ MeV [2] and $\mathrm{f_{D_s}} = 230 \pm 24$ MeV [3], and lattice QCD calculations predict $\mathrm{f_{D_s}} = 255 \pm 30$ MeV [4].

The extraction of CKM matrix elements from $\mathrm{B^0} - \overline{\mathrm{B}}^0$ oscillation measurements relies on these theoretical models for calculation of the decay constant for B mesons, f_B, since a measurement of f_B from $\mathrm{B}^- \rightarrow \ell^- \bar{\nu}_\ell$ decays is currently not feasible. It is therefore important to measure $\mathrm{f_{D_s}}$ to test the theoretical models used in the f_B calculation.

2. LEP measurements of $\mathrm{BR}(\mathrm{D_s} \rightarrow \tau\nu)$

Since the $\mathrm{D_s} \rightarrow \ell\nu$ decay is helicity suppressed, the τ channel has the largest branching ratio of all leptonic channels. Eq. 1.1 predicts the branching ratio into electrons to be negligible,

*Speaker.
†Heisenberg Fellow of the Deutsche Forschungsgemeinschaft
[1]Charge conjugate decays are implied throughout the paper.

$\mathrm{BR}(\mathrm{D_s} \to \mathrm{e}\nu)/\mathrm{BR}(\mathrm{D_s} \to \tau\nu) < 10^{-5}$, due to the factor m_ℓ^2, whereas the branching ratio into muons, $\mathrm{BR}(\mathrm{D_s} \to \mu\nu)$, is expected to be sizable, $\mathrm{BR}(\mathrm{D_s} \to \mu\nu)/\mathrm{BR}(\mathrm{D_s} \to \tau\nu) = 0.103$.

ALEPH [6] measures the signal by separating $\mathrm{D_s} \to \tau\nu, \tau \to \mathrm{e}\nu\nu, \mu\nu\nu$ and $\mathrm{D_s} \to \mu\nu$ decays from background using linear discriminants. The branching ratio measured by ALEPH is $\mathrm{BR}(\mathrm{D_s} \to \tau\nu) = (5.79 \pm 0.76\ (\mathrm{sta}) \pm 1.16\ (\mathrm{sys}) \pm 1.35\ (\phi\pi))\%$. The last error is due the uncertainty on the $\mathrm{D_s}$ production rate which is dominated by the uncertainty on $\mathrm{BR}(\mathrm{D_s} \to \phi\pi) = (3.6 \pm 0.9)\%$. This uncertainty is common to almost all measurements of leptonic $\mathrm{D_s}$ decays, and is therefore treated separately.

DELPHI [7], L3 [8] and OPAL [9] have measured $\mathrm{BR}(\mathrm{D_s} \to \tau\nu)$ by reconstructing the decay sequence

$$
\begin{array}{llll}
\mathrm{e^+e^-} \to \mathrm{Z} \to \mathrm{c\bar{c}} \to & \mathrm{D_s^\star}\ \mathrm{X} & & \\
& \hookrightarrow\ \gamma\ \mathrm{D_s} & & \\
& & \hookrightarrow\ \tau\ \nu & \\
& & & \hookrightarrow\ \ell\ \nu\ \nu\ \ (\ell = e, \mu).
\end{array}
\tag{2.1}
$$

Only $\mathrm{D_s} \to \tau\nu$ events from $\mathrm{Z} \to \mathrm{c\bar{c}}$ decays are considered, since a measurement of $\mathrm{BR}(\mathrm{D_s} \to \tau\nu)$ in $\mathrm{Z} \to \mathrm{b\bar{b}}$ events is systematically limited by the large uncertainty on the production rate of $\mathrm{D_s}$ mesons in $\mathrm{Z} \to \mathrm{b\bar{b}}$ events.

For a sample of preselected hadronic Z events with one identified electron or muon, the kinematics are required to be consistent with $\mathrm{D_s} \to \tau\nu \to \ell^-\bar{\nu}_\ell\nu_\tau\bar{\nu}_\tau$ decays. In the final step of the analysis $\mathrm{D_s^\star} \to \gamma\mathrm{D_s}$ decays are reconstructed in this $\mathrm{D_s} \to \tau\nu$ enhanced sample by forming the invariant mass of the photon and the $\mathrm{D_s}$ candidate. This reduces the dependence on the Monte Carlo simulation of the background and increases the purity of the $\mathrm{D_s}$ sample.

The decay $\mathrm{D_s} \to \mu\nu$ is included in the signal definition and the final result is corrected for this contribution.

$$
\begin{aligned}
\mathrm{BR}(\mathrm{D_s} \to \tau\nu) = & \frac{N_{\mathrm{cand}}}{2N_{\mathrm{Z}} \cdot R_{\mathrm{C}} \cdot f(c \to \mathrm{D_s}) \cdot P_V(\mathrm{D_s^\star}, \mathrm{D_s}) \cdot \mathrm{BR}(\mathrm{D_s^\star} \to \gamma\mathrm{D_s})} \\
& \times \frac{1}{\mathrm{BR}(\tau \to l\bar{\nu}_l\nu_\tau) \cdot \epsilon(\mathrm{D_s} \to \tau\nu) + \frac{\mathrm{BR}(\mathrm{D_s} \to \mu\nu)}{\mathrm{BR}(\mathrm{D_s} \to \tau\nu)} \cdot \epsilon(\mathrm{D_s} \to \mu\nu)},
\end{aligned}
\tag{2.2}
$$

N_{cand} is the number of background-subtracted candidates in the signal region, N_{Z} the number of Z decays, $R_{\mathrm{c}} = 0.1729 \pm 0.0032$ [10] the partial width of the Z decaying into a pair of charm quarks, $f(c \to \mathrm{D_s}) = 0.130 \pm 0.027$ [10] the production rate of $\mathrm{D_s}$ mesons in charm jets, $\epsilon(\mathrm{D_s} \to \tau\nu)$ the efficiency for the signal and $\epsilon(\mathrm{D_s} \to \mu\nu)$ the efficiency for reconstructing $\mathrm{D_s^\star} \to \gamma\mathrm{D_s} \to \gamma\mu^-\bar{\nu}_\mu$ decays.

$P_V(\mathrm{D_s^\star}, \mathrm{D_s})$ is the ratio of $\mathrm{c\bar{s}}$ mesons produced in a vector state ($\mathrm{D_s^\star}$) with respect to the sum of the pseudoscalar ($\mathrm{D_s}$) and vector states. For non-strange D mesons, $P_V(\mathrm{D^\star}, \mathrm{D})$ has been measured by ALEPH [11], DELPHI [12] and OPAL [13]. The averaged value is $P_V(\mathrm{D^\star}, \mathrm{D}) = 0.61 \pm 0.03$ [14]. To extrapolate this ratio to $\mathrm{D_s}$ mesons, the effect of the decays of $L = 1$ $\mathrm{D^{\star\star}}$ resonances and quark mass effects need to be taken into account. $\mathrm{D^{\star\star}}$ resonances contribute only in the case of non-strange mesons. This effect was estimated by OPAL to be smaller than the experimental uncertainty [13] and is therefore neglected. Applying the correction factor for quark mass effects from [14] yields $P_V(\mathrm{D_s^\star}, \mathrm{D_s}) = 0.64 \pm 0.05$ where the full size of the correction is included in the uncertainty. This value is consistent with the ALEPH measurement of $P_V(\mathrm{D_s^\star}, \mathrm{D_s}) = 0.60 \pm 0.19$ [11].

Using these input values and $P_V(\mathrm{D_s^\star}, \mathrm{D_s}) = 0.64 \pm 0.05$ we obtain the following measurements:

$$\begin{aligned}
\text{ALEPH} &: \mathrm{BR}(\mathrm{D_s} \to \tau\nu) = (5.79 \pm 0.76\ (\mathrm{sta}) \pm 1.16\ (\mathrm{sys}) \pm 1.35\ (\phi\pi))\% \qquad (2.3)\\
\text{DELPHI} &: \mathrm{BR}(\mathrm{D_s} \to \tau\nu) = (6.91 \pm 3.45\ (\mathrm{sta}) \pm 1.72\ (\mathrm{sys}) \pm 1.43\ (\phi\pi) \pm 0.55\ (P_V))\%\\
\text{L3} &: \mathrm{BR}(\mathrm{D_s} \to \tau\nu) = (6.34 \pm 2.44\ (\mathrm{sta}) \pm 1.38\ (\mathrm{sys}) \pm 1.32\ (\phi\pi) \pm 0.51\ (P_V))\%\\
\text{OPAL} &: \mathrm{BR}(\mathrm{D_s} \to \tau\nu) = (6.25 \pm 1.91\ (\mathrm{sta}) \pm 1.12\ (\mathrm{sys}) \pm 1.30\ (\phi\pi) \pm 0.50\ (P_V))\%
\end{aligned}$$

The average is $\mathrm{BR}(\mathrm{D_s} \to \tau\nu) = (6.05 \pm 1.04 \pm 1.34\ (\phi\pi) \pm 0.22\ (P_V))\%$.

3. Measurements of BR($\mathrm{D_s} \to \mu\nu$)

Before LEP several experiments have measured the branching ratio of the decay $\mathrm{D}_s \to \mu\nu$ to derive $\mathrm{f_{D_s}}$. These measurements also depend on external input which is partially correlated. In the following I will therefore shortly review the measurements and give an updated result wherever external inputs have changed.

- The WA75 experiment [15] has used 350 GeV π nucleon interactions with an emulsion target to measure the ratio

$$r\frac{\mathrm{BR}(\mathrm{D_s} \to \mu\nu)}{\mathrm{BR}(\mathrm{D^0} \to \mu\nu\mathrm{X})} = (1.25^{+0.55}_{-0.44}\ (\mathrm{sta})^{+0.24}_{-0.20}\ (\mathrm{sys})) \cdot 10^{-2}, \qquad (3.1)$$

  where r is ratio of the production cross-section for $\mathrm{D_s}$ and $\mathrm{D^0}$ mesons in πn scatttering The ratio r can be derived from a BEATRICE measurement of these cross-section in the forward direction ($x_\mathrm{F} > 0$) to be $r = 0.166 \pm 0.026 \pm 0.041\ (\phi\pi)$ [16] [2]. With $\mathrm{BR}(\mathrm{D^0} \to \mu\nu\mathrm{X}) = 0.066 \pm 0.008$ [5] we obtain

$$\mathrm{BR}(\mathrm{D_s} \to \mu\nu) = (0.50^{+0.22}_{-0.18}\ (\mathrm{sta})^{+0.14}_{-0.13}\ (\mathrm{sys}) \pm 0.12(\phi\pi))\%. \qquad (3.2)$$

- Using interactions of 350 GeV π^- on copper and tungsten targets, the BEATRICE experiment has measured the ratio [17]

$$\frac{\mathrm{BR}(\mathrm{D_s} \to \mu\nu)}{\mathrm{BR}(\mathrm{D_s} \to \phi(\to \mathrm{K^+K^-})\pi)} = 0.47 \pm 0.13\ (\mathrm{sta}) \pm 0.04\ (\mathrm{sys}) \pm 0.06\ (\phi\pi) \qquad (3.3)$$

  which yields $\mathrm{BR}(\mathrm{D_s} \to \mu\nu) = 0.83 \pm 0.23\ (\mathrm{sta}) \pm 0.06\ (\mathrm{sys}) \pm 0.18\ (\phi\pi)$.

[2]The correlation introduced by using the same BEATRICE $\mathrm{D_s} \to \mathrm{K^+K^-}\pi$ data to normalise the BEATRICE and the WA75 measurement is found to have a negligible effect on the combined result

- The E653 experiment [18] has measured the ratio

$$\frac{\mathrm{BR}(\mathrm{D_s} \to \mu\nu)}{\mathrm{BR}(\mathrm{D_s} \to \phi\mu\nu)} = 0.16 \pm 0.06 \text{ (sta)} \pm 0.03 \text{ (sys)} \tag{3.4}$$

  in 600 GeV π nucleon interactions on an emulsion. Using $\mathrm{BR}(\mathrm{D_s} \to \phi\mu\nu) = 0.020 \pm 0.005$ [5] this yields $\mathrm{BR}(\mathrm{D_s} \to \mu\nu) = (0.32 \pm 0.12 \text{ (sta)} \pm 0.07 \text{ (sys)} \pm 0.08 \ (\phi\pi))\%$.

- The BES experiment [19] has measured $\mathrm{BR}(\mathrm{D_s} \to \mu\nu) = (1.5^{+1.3}_{-0.6} \text{ (sta)}^{+0.3}_{-0.2} \text{ (sys)})\%$. in the process $\mathrm{e^+e^-} \to \mathrm{D_s D_s}$ by tagging leptonic $\mathrm{D_s}$ decays recoiling to a hadronic $\mathrm{D_s}$ decay. The uncertainty is mainly statistical and no correlation needs to be taken into account.

- The most recent CLEO measurement [20] of the ratio

$$\frac{\mathrm{BR}(\mathrm{D_s} \to \mu\nu)}{\mathrm{BR}(\mathrm{D_s} \to \phi\pi)} = 0.173 \pm 0.023 \text{ (sta)} \pm 0.035 \text{ (sys)} \tag{3.5}$$

  is based on $\mathrm{e^+e^-} \to \mathrm{c\bar{c}}$ events measured at energies close to the $\Upsilon(4S)$ resonance. The branching ratio is derived to be $\mathrm{BR}(\mathrm{D_s} \to \mu\nu) = (0.62 \pm 0.08 \text{ (sta)} \pm 0.13 \text{ (sys)} \pm 0.16 \ (\phi\pi))\%$.

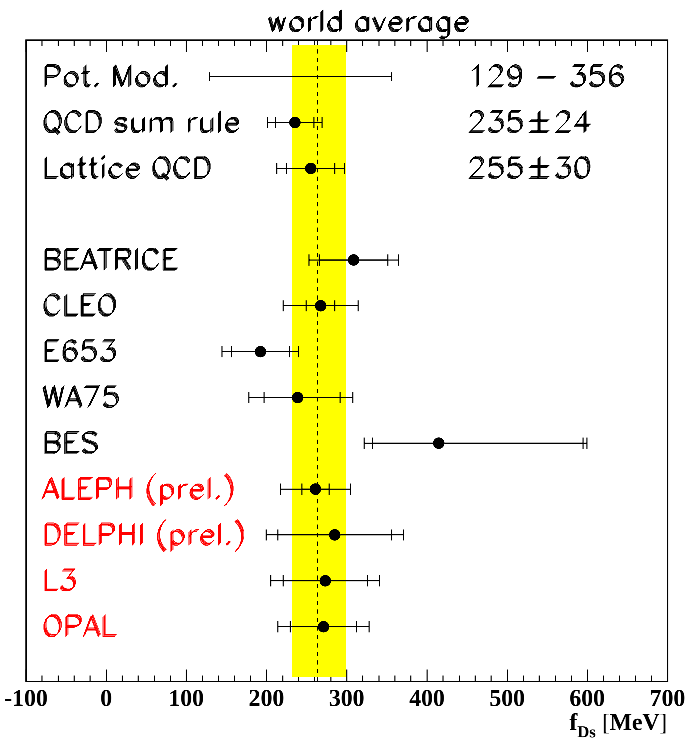

Figure 1: Comparison of the $f_{\mathrm{D_s}}$ measurements by the individual experiments with the theoretical predictions. The inner error bar is the statistical uncertainty and the outer error bar the total uncertainty. The dashed line is the world average calculated in this note and the yellow band the total uncertainty.

Experiment	f_{D_s} (MeV)	f_{D_s} (MeV)
ALEPH (prel.)	$261 \pm 17 \pm 26 \pm 30$	$285 \pm 20 \pm 40$
DELPHI (prel.)	$285 \pm 71 \pm 35 \pm 30 \pm 11$	$330 \pm 82 \pm 50$
L3	$273 \pm 52 \pm 30 \pm 29 \pm 11$	$309 \pm 58 \pm 50$
OPAL	$271 \pm 41 \pm 24 \pm 28 \pm 11$	$286 \pm 44 \pm 41$
Beatrice	$309 \pm 43 \pm 11 \pm 33$	$323 \pm 44 \pm 36$
CLEO	$267 \pm 18 \pm 27 \pm 33$	$280 \pm 19 \pm 44$
E653	$192 \pm 36 \pm 20 \pm 24$	$194 \pm 35 \pm 24$
WA75	$239\ ^{+53}_{-42}\ ^{+33}_{-30} \pm 30$	$232 \pm 45 \pm 52$
BES	$418\ ^{+180}_{-83}\ ^{+41}_{-28}$	$430\ ^{+150}_{-130} \pm 40$

Table 1: Decay constants f_{D_s} measured by the experiments. The first value shown is calculated with the numbers given in the paper. The uncertainties are the statistical uncertainties, the uncorrelated systematic uncertainties, the uncertainties due to $BR(D_s \to \phi\pi)$, and the uncertainties due to P_V. The second value is the original value published by the experiment with the statistical and the sum of all systematic uncertainties. The relative uncertainties of the BES measurement are different because in the original analysis f_{D_s} has been extracted directly from the data [19].

Averaging these results yields $BR(D_s \to \mu\nu) = (0.53 \pm 0.09 \pm 0.12\ (\phi\pi))\%$ taking into account the correlation due to the uncertainty on the branching ratio $BR(D_s \to \phi\pi)$. The first error is due to the uncorrelated statistical and systematic uncertainties. The purely statistical contribution to the uncertainty is 10 MeV. The uncorrelated uncertainties yield $\chi^2/\mathrm{ndf} = 6.5/4$. The result is in good agreement with the ALEPH measurement [6] $BR(D_s \to \mu\nu) = (0.68 \pm 0.16 \pm 0.13\ (\phi\pi))\%$ which is not used in the averages due to its large correlations with the ALEPH $D_s \to \tau\nu$ measurement.

4. Decay constant f_{D_s}

The decay constant f_{D_s} is calculated using (1.1) with $G_F = (1.16639 \pm 0.00001) \times 10^{-5}$ GeV^{-2}, $|V_{cs}| = 0.9891 \pm 0.016$, $m_{D_s} = 1.9686 \pm 0.0006$ GeV, $\tau_{D_s} = (0.496 \pm 0.01) \times 10^{-12}$ s, $m_\tau = 1.77703 \pm 0.00030$ GeV [5]. Most uncertainties are negligible, only the uncertainties on $|V_{cs}|$ and τ_{D_s} contribute slightly to the final uncertainty.

In table 1 the values of f_{D_s} are compared to the original values published by the experiments. The average of all measurements yields

$$f_{D_s} = 264 \pm 15 \pm 33\ (\phi\pi) \pm 2\ (P_V) \pm 4\ (V_{cs}, \tau_{D_s})\ \mathrm{MeV}, \qquad (4.1)$$

where the first uncertainty is due to the sum of the statistical and the uncorrelated systematic uncertainties of the measurements, and the other uncertainties are due to the various correlated uncertainties. Using only the uncorrelated uncertainties yields $\chi^2/\mathrm{ndf} = 7.4/8$.

In figure 1 the f_{D_s} measurements of the experiments are shown together with the average calculated in this note. They are also compared to the theoretical predictions. Within the uncertainties they are consistent with the data. The precision of the measurement can only be increased by reducing the uncertainty on $BR(D_s \to \phi\pi)$ or by using measurement methods which do not depend on $BR(D_s \to \phi\pi)$.

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