Measurement of $\mathrm{D_s} \to \tau\nu_\tau$ and Search for $\mathrm{B} \to \tau\nu_\tau$ with the L3 detector

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Abstract. The purely leptonic decays of heavy mesons $\mathrm{D_s} \to \tau\nu_\tau$ and $\mathrm{B} \to \tau\nu_\tau$ are studied in a sample of 1.5M $\mathrm{Z} \to \mathrm{q\bar{q}}(\gamma)$ events collected in 1994 by the L3 detector at LEP. A signal for the decay chain $\mathrm{D_s^*} \to \gamma\mathrm{D_s}$, $\mathrm{D_s} \to \tau\nu_\tau$, $\tau \to \ell\nu_\ell\nu_\tau$ is observed in the invariant mass distribution $M(\gamma\mathrm{D_s})$. From this signal, a branching ration of $\mathcal{B}(\mathrm{D_s} \to \tau\nu_\tau) = 0.074 \pm 0.028(\mathrm{stat}) \pm 0.016(\mathrm{syst}) \pm 0.018(\mathrm{norm})$ is derived, corresponding to a decay constant $f_{\mathrm{D_s}} = 309 \pm 58(\mathrm{stat}) \pm 33(\mathrm{syst}) \pm 38(\mathrm{norm})$ GeV. No signal is observed for the decay $\mathrm{B} \to \tau\nu_\tau$, and an upper limit of $\mathcal{B}(\mathrm{B} \to \tau\nu_\tau) < 5.7 \times 10^{-4}$ at 90 % CL is set. These results have been published in [1].

INTRODUCTION

In purely leptonic decays of a heavy meson, the effect of the strong interaction can be described by one single parameter, f_M, the decay constant. The leptonic width of a meson with mass M, in terms of this decay constant, is given by [2]:

$$\Gamma_{\text{leptonic}} = \frac{G_F^2}{8\pi} |V_{Qq}|^2 f_M^2 M m_\ell^2 \left(1 - \frac{m_\ell^2}{M^2}\right)^2$$

where m_ℓ is the lepton mass, G_F the Fermi constant and V_{Qq} the CKM matrix element corresponding to the heavy quark flavor Q and the spectator flavor q.

As the masses are well known, a value of $f_M|V_{Qq}|$, can be extracted from measurements of these decays and they can be compared directly to Lattice QCD predictions. In addition, the values of decay constants are needed for the absolute normalization of other predictions, including $\mathrm{B^0} - \mathrm{\bar{B}^0}$ mixing and semileptonic decays. Finally, as the ratios of decay constants are, in general, predicted more accurately then the constants themselves; measurements of one constant can be used to improve the prediction of others.

Theoretical predictions of the various decay constants vary between 100–300 MeV . The expected branching ratios (shown in Table 1) are small, but

[1] Representing the L3 collaboration

TABLE 1. The predicted branching fractions, assuming $V_{cd} = 0.21$, $V_{cs} = 0.97$, $V_{ub} = 0.003$ and $f_B = f_D = f_{D_s} = 200$ MeV

Decay channel	Branching fraction	Decay channel	Branching fraction	Decay channel	Branching fraction
$D \to \tau\nu_\tau$	8×10^{-4}	$D_s \to \tau\nu_\tau$	2×10^{-2}	$B \to \tau\nu_\tau$	7×10^{-5}
$D \to \mu\nu_\mu$	3×10^{-4}	$D_s \to \mu\nu_\mu$	3×10^{-3}	$B \to \mu\nu_\mu$	3×10^{-7}
$D \to e\nu_e$	7×10^{-9}	$D_s \to e\nu_e$	7×10^{-8}	$B \to e\nu_e$	7×10^{-11}

one can see that a measurement of f_{D_s}, using the CKM and mass favoured $D_s \to \tau\nu_\tau$ channel, is within reach of LEP experiments. This decay has been reported by BES [3] and E653, and several experiments [4] have seen the decay $D_s \to \mu\nu_\mu$. Unfortunately, the decay of $B \to \tau\nu_\tau$ is suppressed. However, some models [6] containing charged Higgs bosons predict an enhancement of this branching ratio. So far only upper limits on this process have been given [5].

MEASUREMENT OF $D_s \to \tau\nu_\tau$

At LEP, D_s is produced copiously in $Z \to c\bar{c}$ decays. Using 1.475M $Z \to q\bar{q}(\gamma)$ events, corresponding to 49.6 pb^{-1} at $\sqrt{s} = 91.2$ GeV collected in 1994, L3 has analyzed the fragmentation and decay chain $c \to D_s^* X$, $D_s^* \to D_s\gamma$, $D_s \to \tau\nu_\tau$ and finally $\tau \to \ell\bar{\nu}_\ell\nu_\tau$ where $\ell = e, \mu$. These events are hadronic events with large missing momentum, a lepton and a photon in one hemisphere. First the D_s momentum is reconstructed; the D_s candidate is then combined with the photon, and one looks for a D_s^* signal in the γD_s invariant mass distribution.

The D_s energy and momentum are determined by a constraint fit to the reconstructed particles in the event, excluding the D_s decay products. Energy and momentum conservation are used to define the D_s momentum from the fitted energies, which are varied whilst subjected to the D_s mass constraint:

$$\chi^2 = \sum_{i \neq \ell} \frac{(E_i - E_i^{\mathrm{meas}})^2}{\sigma^2_{E_i^{\mathrm{meas}}}}, \; E^2_{D_s} - p^2_{D_s} = M^2_{D_s}$$

where $\vec{p}_{D_s} = -\sum_{i\neq\ell} \vec{p}_i$ and $E_{D_s} = \sqrt{s} - \sum_{i\neq\ell} E_i$

This technique was verified on $q\bar{q}\gamma$ events, where the γ was reconstructed in a similar fashion. This measurement of the γ energy and direction was then compared to the direct measurement. The comparison shows good agreement between data and simulation, and yields the following resolution on the D_s energy and direction: $\sigma_\theta = 61$ mrad, $\sigma_\phi = 53$ mrad and $\sigma_E = 3.0$ GeV.

The main background consists of semileptonic decays, which are suppressed by two cuts. The first cut uses the feature that for semileptonic decays the reconstruction algorithm underestimates the energy of the D_s candidate: the D_s energy must exceed 30 GeV. The second cut exploits the fact that particles produced in the fragmentation process carry, on average, less energy than those

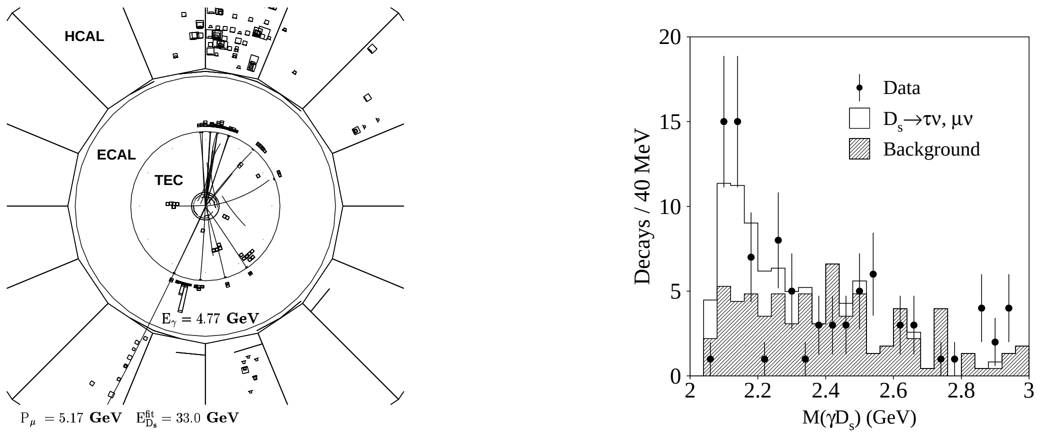

FIGURE 1. Shown on the left is a typical $\mathrm{D_s} \to \tau\nu_\tau$ candidate as observed in the L3 detector and on the right the reconstructed $\gamma\mathrm{D_s}$ invariant mass distribution.

produced in semileptonic $\mathrm{D_s}$ decays: the leading particle, with charge opposite the lepton, in the same hemisphere, must have less than 3 GeV of energy.

Finally, the $\mathrm{D_s}$ candidate is combined with a photon in the same hemisphere to form a $\mathrm{D_s^*}$. Only photons with an energy between 3 and 5 GeV are considered: in the range above 5 GeV no signal is expected, whereas below 3 GeV background dominates. After all cuts, the signal selection efficiency is $1.7\% \pm 0.3\%$. One of the selected candidates is shown in Figure 1.

The signal is extracted from the $M(\gamma\mathrm{D_s})$ distribution (shown in Figure 1) by a binned likelihood fit, which fixes both the background shape and normalization to the Monte Carlo prediction. The fit yields a total of 15.6 ± 6.0 signal events, which corresponds to the following branching ratio:

$$\mathcal{B}(\mathrm{D_s} \to \tau\nu_\tau) = 0.074 \pm 0.028\ (\mathrm{stat}) \pm 0.016\ (\mathrm{sys}) \pm 0.018\ (\mathrm{norm}) \qquad (1)$$

The systematic error is due to uncertainties in the detector resolution, the background and the fragmentation functions. The normalization error is due to the uncertainties in the $\mathrm{D_s^*}/\mathrm{D_s}$ ratio [7] and the $\mathrm{D_s}/\mathrm{c}$ fraction [8].

Determination of $f_{\mathrm{D_s}}$

Assuming the PDG values [9] for $\tau_{\mathrm{D_s}}$, $M_{\mathrm{D_s}}$ and V_{cs}, the measured branching ratio (Eq. 1) corresponds to the following decay constant:

$$f_{\mathrm{D_s}} = 309 \pm 58\ (\mathrm{stat}) \pm 33\ (\mathrm{syst}) \pm 38\ (\mathrm{norm})\ \mathrm{GeV}.$$

When combined with other leptonic decay measurements [3,4] from BES, CLEO, E653 and WA75 the following average value is obtained[2]:

$$f_{\mathrm{D_s}} = 245 \pm 27\ \mathrm{MeV}$$

[2] The CLEO and WA75 results have been updated for new measurements of their normalisation modes.

SEARCH FOR $\mathrm{B}\to\tau\nu_\tau$

The reconstruction and selection of the fragmentation and decay chain $\mathrm{Z}\to\mathrm{b}\bar{\mathrm{b}}$, $\mathrm{b}\to\mathrm{B}\to\tau\nu_\tau$, $\tau\to\mathrm{X}\nu_\tau$ proceeds similar to the $\mathrm{D_s}$. As for $\mathrm{D_s}$, the reconstructed B energy must be larger than 30 GeV to reduce the semileptonic background. A τ candidate is identified in the least energetic hemisphere by the presence of a lepton or hadron of at least 1 GeV, inconsistent with the primary vertex. All other tracks in the hemisphere are required to have energy less than 2 GeV and must be consistent with the primary vertex. If the τ decays hadronically, an additional cut is made on the invariant mass of all reconstructed particles, except the τ decay products, in a cone around the τ.

In the case of leptonic τ decays, the signal content is determined from the energy spectrum of the lepton; for hadronic τ decays, the distribution of the energy (again excluding the τ decay products) in a cone around the τ direction is used. No signal is observed, and the following upper limit is derived:

$$\mathcal{B}(\mathrm{B}\to\tau\nu_\tau) < 5.7\times10^{-4} \text{ at } 90\%\mathrm{CL}$$

This improves the previously published result from the ALEPH and CLEO collaborations [5].

REFERENCES

1. M.Acciarri *et all.*, L3 collaboration, Phys.Lett. B396(1997) 327.
2. J.Richman and P.Burchat, Rev.Mod.Phys. 67(1995) 893.
3. J.Z.Bai *et all.*, BES collaboration, Phys.Rev.Lett. 74(1995) 4599.
4. S.Aoki *et all.*, WA75 collaboration, Prog.Theor.Phys. 89(1993) 131;
   D.Acosta *et all.*, CLEO collaboration, Phys.Rev. D49(1994) 5690;
   D.Gibaut *et all.*, CLEO collaboration, note CONF 95-22;
   K.Kodama *et all.*, E653 collaboration, Phys.Lett. B382(1996) 299.
5. D.Buskulic *et all.*,ALEPH collaboration, Phys.Lett. B343(1995) 444;
   M.Artuso *et all.*, CLEO collaboration, Phys.Rev.Lett. 75(1995) 785.
6. W.S.Hou, Phys.Rev. D48(1993) 2342
7. W.Y.Chen *et all.*, CLEO collaboration, Phys.Lett. B226(1989) 192;
   H.Albrecht *et all.*, ARGUS collaboration, Z.Phys. C53(1992) 361;
   B.Buskulic *et all.*, ALEPH collaboration, Z.Phys. C69(1996) 585;
   G.Alexander *et all.*, OPAL collaboration, Z.Phys. C72(1996) 1.
8. P.Abreu *et all.*, DELPHI collaboration, Z.Phys. C59(1993) 533;
   B.Buskulic *et all.*, ALEPH collaboration, Z.Phys. C62(1994) 1;
   G.Alexander *et all.*, OPAL collaboration, Z.Phys. C67(1995) 27.
9. R.M.Barnett *et all.*, Particle Data Group Phys.Rev. D54(1996) 1.