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A measurement of the D_s lifetime

TASSO Collaboration

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Abstract. The lifetime of the D_s meson has been measured using the TASSO detector at PETRA and found to be $(5.7^{+3.6}_{-2.6} \pm 0.9) \times 10^{-13}$ s. The method used was to reconstruct fully the decay vertex of the channel $D_s \rightarrow \phi \pi^{\pm}$, $\phi \rightarrow K^+ K^-$.

The TASSO collaboration has previously published [1] results on D_s meson (formerly called the $F^{\pm}$ meson) production resulting from $e^+ e^-$ annihilation at high energies. The majority of the data reported in that publication were taken prior to the installation of the TASSO high precision vertex chamber (VXD), and so that analysis could not take advantage of the improved resolution of track parameters. The present analysis is a new procedure utilizing the VXD information and devised to obtain a final D_s sample unbiased with respect to the D_s lifetime. It is based on a sample of 39,800 hadronic events predominantly at a center of mass energy of 35 GeV, and including 9000 events at 44 GeV. This results from an integrated luminosity of 140 pb^{-1}, taken in the years 1984–86. Annihilation events were selected using the procedure described in [2]. A general description of the TASSO detector [3] and the vertex chamber [4, 5] may be found elsewhere. Since the tracking capabilities are central to this study, a short description of the two major drift chamber systems is given below.

Briefly, TASSO has a large cylindrical drift chamber (DC) consisting of 15 layers of drift cells between 36 cm and 122 cm radius. Six of these 15 layers are made up of small angle stereo wires and provide all the polar angle information used in the track fits. Inside the DC (and also inside a central proportional chamber used for triggering purposes) is the high precision vertex chamber operating at three atmospheres. The VXD consists of eight axial drift cell layers whose innermost layer is 8.1 cm and outermost is 14.9 cm from the beam axis. The drift cell resolution of the VXD has been measured to be 90 μm in $\mu^+ \mu^-$ pair production and 120 μm for hadronic events. This resolution facilitates precise vertex reconstruction.

The D_s meson was searched for by looking at the decay chain $D_s^{\pm} \rightarrow \phi \pi^{\pm}$, $\phi \rightarrow K^+ K^-$. An attempt was made to associate each charged track reconstructed in the DC with digitizations in the VXD. Those tracks, with $p_{\perp}$ (with respect to the beam) greater than 0.1 GeV, which were successfully associated with four or more (out of a possible eight) VXD hits were retained for the rest of the analysis. Pairs of accepted, oppositely charged tracks were then combined to try to form the ϕ meson, assuming the K mass for each.

Only a very loose cut of $M(K^+ K^-) < 1.05$ GeV was made because in later stages of the analysis the track parameters, and hence the reconstructed masses, are improved further by reconstructing decay vertices. Track pairs were also rejected if, when electron masses were assumed, the pair mass was less then 0.1 GeV. A third track was then combined with the ϕ candidate, assuming it to be a pion. To eliminate events with large vertex errors due to multiple scattering, only tracks of momentum greater than 0.5 GeV/c were used. A vertex fit [6] was then performed on this triplet of charged tracks by requiring there exist a point in x, y, and z which is common to all three tracks. The triplet of tracks was retained if the probability associated with this three constraint geometric vertex fit was greater than 1%. The mass of the hypothetical $K^+ K^-$ subsystem was recalculated from the track parameters resulting from this vertex fit. Those triplets for which this mass was within 0.015 GeV of the ϕ mass were used in the next stage of the selection process if $x = E_{KK\pi}/E_{\text{beam}} \geqq 0.6$. This final cut, which essentially eliminates those D_s mesons produced in the weak decay of bottom hadrons, dramatically reduces the combinatorial background. The $KK\pi$ mass spectrum resulting from these cuts and calculated using the track parameters from the geometric vertex fit is shown in Fig. 1a.

A kinematic vertex fit [7] was then performed on the triplet of tracks by constraining the $K^+ K^-$ candidates to the ϕ mass, 1.020 GeV. All the track parameters, including the vertex coordinates, of all three tracks were allowed to vary in order to satisfy the requirement of a common vertex. In this way the momentum resolution of the pion is improved as well as improving those tracks resulting from the decay of the ϕ. The $KK\pi$ mass spectrum, after the kinematic constraint to the ϕ mass is imposed, is shown in Fig. 1b. The D_s signal is consistent with the accepted mass [8] of 1.971 GeV and the expected 23 ± 3 MeV mass resolution determined from Monte Carlo simulations. The D_s candidates were accepted for the lifetime studies if they satisfied $1.930 \leqq M(KK\pi) \leqq 2.010$ GeV. No further cuts were made on this sample.

From measurements of $D^{\pm}$ production in the range $0.6 < x < 1.0$ at $W = 29$ GeV [9] and from the measured $D^{\pm} \rightarrow \phi \pi^{\pm}$ branching ratio (1.0 ± 0.3)% [8] and $D^+ \rightarrow K^- \pi^+ \pi^+$ (11.4 ± 1.1)% [10], we expect to see 5 ± 2 $K^+ K^- \pi^{\pm}$ combinations in the D^+ mass region. The background was determined by normalizing a line to the mass distribution outside the $D^{\pm}$ and D_s regions. The result is shown as a curve superimposed on Fig. 1b. In the region near 1.870 GeV we find $4.4 \pm 4.2\, D^+$ mesons. Between 1.930 GeV and 2.010 GeV there is a D_s signal of 8.8 events above a background of 5.2 events.

A control sample was also selected using a very

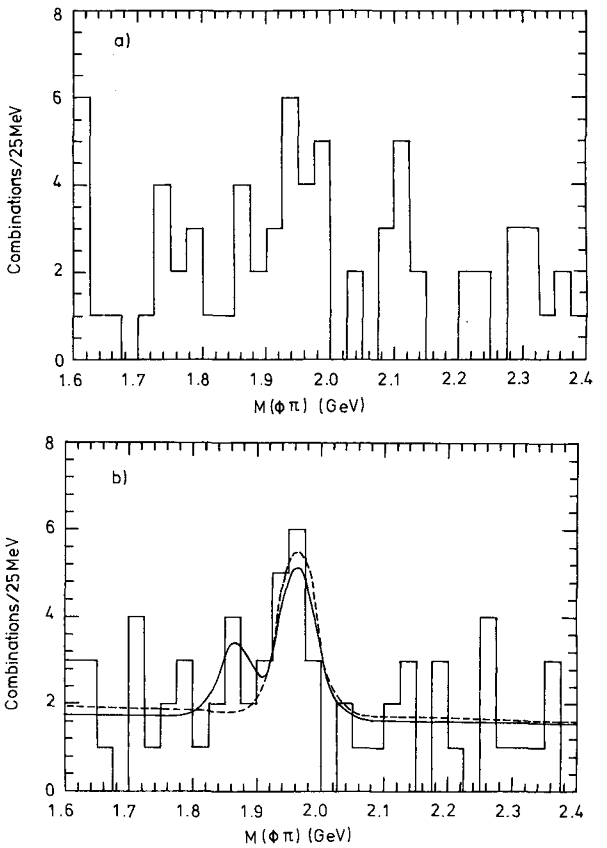

Fig. 1a, b. $K^+K^-\pi^\pm$ mass spectrum for $E_{KK\pi}/E_{\text{beam}} \geq 0.6$. **a** Common vertex constraint, $m(K^+K^-)$ within 0.015 GeV of ϕ mass selected. **b** ϕ mass constraint imposed. Dashed curve – D_s signal and background (straight line fit to sidebands), normalized to data, peak fixed at 1971 MeV, width from experimental resolution; solid curve – same, including estimated $D^\pm$ contribution

similar algorithm but requiring that the mass of the "phi" candidate be in the range 1.05 GeV to 1.15 GeV. The effect of the kinematic constraint was simulated by dividing the K^+K^- mass range for this sample into three equal segments and constraining all "phi" candidates to the nearest central mass. There is no significant enhancement of the D_s mass region.

We generated Monte Carlo D_s's to calculate our reconstruction efficiency. The simulated events were passed through the same analysis chain as the experimental data. Averaged over all $x \geq 0.6$ the reconstruction efficiency for D_s's, including the vertex quality and mass resolution cuts, is 16% for the channel $D_s \rightarrow \phi\pi$, $\phi \rightarrow K^+K^-$.

D_s production at $x \geq 0.6$ is expected to come from the fragmentation of c and $\bar{c}$ quarks produced in the primary e^+e^- interaction. The D_s should carry a large fraction of the beam energy [11]. To obtain a branching fraction, we need to estimate the fraction of D_s mesons produced in the region $x < 0.6$. The world data have been parameterized by Bethke in terms of $z \equiv (E + p_{\|})_{\text{meson}}/(E + p_{\|})_{\text{quark}}$. Because of initial bremsstrahlung and final state gluon emission, the spectrum in x is softer than in z. Using a Monte Carlo program to calculate these effects [12], he finds a mean z for D_s production of $\langle z \rangle = 0.604 \pm 0.023$ [13]. The most commonly used expression to describe the generated fractional energy spectrum is the one proposed by Peterson et al. [14]:

$$f(z) = \frac{1}{z\left(1 - \frac{1}{z} - \frac{\varepsilon}{1-z}\right)^2}$$

where ε is a free parameter related to the heavy quark mass. For this distribution, $\langle z \rangle = 0.6$ corresponds to $\varepsilon = 0.13$. Our estimate of the fraction of events with $x \geq 0.6$ comes from generating samples of D_s with $\varepsilon = 0.13^{+0.02}_{-0.03}$. The region $x \geq 0.6$ is estimated to contain $(39 \pm 5)\%$ of all D_s resulting from primary charm production. Using an s/d quark suppression factor of 0.33 ± 0.02 [15], we obtain a value of the branching fraction $D_s^\pm \rightarrow \phi\pi^\pm$ of $(3.3 \pm 1.6 \pm 1.0)\%$, where the first error is statistical and the second is from uncertainties in the fragmentation. This branching fraction is different from our previous measurement [1]. It is to be compared to the world average of $(3.6 \pm 0.3)\%$ [16].

The lifetime measurement technique is similar to the methods we have previously used for the τ and D^0 lifetimes [5, 17]. The measurement of an individual D_s meson decay distance is made by using the reconstructed vertex, the beam spot centre and size, and the D_s direction in the determination of the most probable production and decay points. In the horizontal direction the average rms width of the beam spot is approximately 375 μm (550 μm at 44 GeV) and is dominated by the beam spread. In the vertical direction the average width used is 100 μm and is dominated by the statistical error in determining the beam spot center.

The three dimensional decay distance may be written in terms of the xy coordinates and polar angle of the reconstructed D_s meson. The most likely laboratory decay distance is given by:

$$l = \frac{x\sigma_{yy} t_x + y\sigma_{xx} t_y - \sigma_{xy}(x t_y + y t_x)}{\sigma_{yy} t_x^2 - 2\sigma_{xy} t_x t_y + \sigma_{xx} t_y^2},$$

where $x = x_{\text{vertex}} - x_{\text{beam}}$ and $y = y_{\text{vertex}} - y_{\text{beam}}$. The σ_{ij} are the elements of the sum of the beam spot and decay vertex error matrices, and t_i is the three dimensional direction cosine of the D_s in the i direction. This is converted to a proper decay time using the relation $\tau = l/\gamma\beta c$.

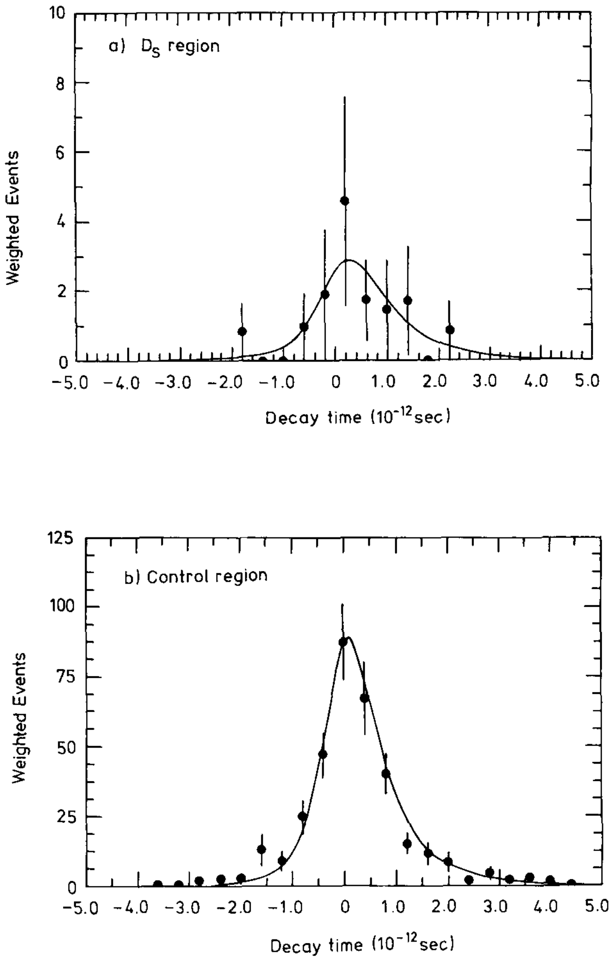

Fig. 2a, b. Weighted distributions of measured decay times. The individual measurements (and errors) are assigned weights proportional to the error^{-2}. Thus a small weight corresponds to a large uncertainty in proper time. **a** The D_s sample. Curve is result of maximum likelihood fit to individual events. **b** Control sample (m_{KK} in upper ϕ sideband, 2.020 GeV$\leq m_{KK\pi} \leq$2.500 GeV). Curve is predicted distribution. (See text)

In Fig. 2a we show the distribution of the measured decay times of the events. In this figure the weight given to each event is proportional to the inverse square of the error on its decay time. There is a large spread owing to variations in projected opening angles and orientation of the flight path relative to the beam ellipse. A typical error on the proper time of an individual event is 5×10^{-13} s.

The D_s lifetime is calculated using a maximum likelihood method [5, 17, 18]. The likelihood function used contains four terms. The first term represents the probability density for the decay of real D_s mesons. It is an exponential convoluted with Gaussians corresponding to the event resolutions. The other three terms represent contributions to the background. This likelihood function is then given by:

$$L = \prod_i \{(1-P_{\text{back}})\, F(\tau_i, \sigma_i; \tau) + P_{\text{back}}(1-P_0-P_+) \cdot G(\tau_i, \sigma_i) + P_{\text{back}}\, P_0\, F_0(\tau_i, \sigma_i) + P_{\text{back}}\, P_+\, F_+(\tau_i, \sigma_i)\}.$$

The probability that a D_s candidate is not a D_s is given by P_{back}, while the fraction of these background events that contain either two or three tracks originating from (and hence may be considered as totally) charged or neutral D mesons are P_+ or P_0 respectively. Contributions from bottom hadrons were shown from Monte Carlo studies to be negligible because of the hard cut on the x of the D_s meson as mentioned above. Monte Carlo studies have also shown that because of the cut on the ϕ mass range the contribution to the background from $\Lambda_c^+ \rightarrow pK^-\pi^+$, the most likely channel to contaminate the D_s sample by mislabelling the proton as a kaon, is negligible. The functions $F(\tau_i, \sigma_i; \tau)$, $F_+(\tau_i, \sigma_i)$ and $F_0(\tau_i, \sigma_i)$ represent the exponential decays of the D_s, $D^\pm$ and D^0 mesons folded with the Gaussian resolution functions, respectively. The hypothesized D_s lifetime is τ, and the τ_i are the measured decay times. The fractions of charged and neutral D meson contamination were found to be $P_{\text{back}}\, P_+ = 7.0\%$ and $P_{\text{back}}\, P_0 = 7.8\%$ respectively. Values of $\tau_{D^+} = 9.3 \times 10^{-13}$ s and $\tau_{D^0} = 4.1 \times 10^{-13}$ sec were used [19]. The maximum likelihood fit yields $\tau = (5.7^{+3.6}_{-2.6}) \times 10^{-13}$ s. The curve shown on top of the data in Fig. 2a is the distribution predicted from the maximum likelihood fit using the distributions of resolutions on individual τ_i found in the data.

Our understanding of the contributions of the background to the D_s lifetime measurement is achieved both by extensive Monte Carlo studies and by studying the lifetime of our control sample. As mentioned above, we selected $KK\pi$ combinations where the mass of the KK subsystem was in the ϕ upper side band. The decay times of the control sample are shown in Fig. 2b. These events correspond to masses 2.02 GeV$\leq M(KK\pi) \leq$2.50 GeV. The curve shows the distribution predicted from a Monte Carlo study. The agreement between this curve and the data shows that the charm fraction of the control sample (17% of combinations having two or three tracks from D^0 and 17% from $D^\pm$) and the time resolution are correctly described. Using these fractions in a likelihood fit to the control sample, we obtain a mean lifetime for prompt particles of $\tau_{uds} = (-0.59 \pm 0.43) \times 10^{-13}$ s. We conclude that we can estimate correctly the background and resolution of the decay time distribution and that the results are unbiased.

The systematic uncertainties in our measurement were studied by varying various parameters in the analysis on the actual D_s meson data sample. The largest single contribution comes from the assumed

VXD resolution. This enters both explicitly and implicitly at various stages of our analysis, including VXD hit association and calculating the uncertainty in the reconstructed decay vertices. From studies of the description of the decay time distribution in the control sample, we conclude that the domain 150 to 100 μm produced a systematic increase in the resulting average lifetime, together with fluctuations about this trend arising from individual VXD hits being deleted as the implied track χ^2 criterion tightens. These effects lead to a systematic error of $\pm 0.7 \times 10^{-13}$ s. The background fraction was varied within the error which produced a change of $\pm 0.4 \times 10^{-13}$ s. Changing the assumed beam size by reasonable amounts produced negligible differences. We verified in Monte Carlo studies, by generating data sets of different assumed D_s lifetimes, that our vertex reconstruction is unbiased within a systematic error of 0.3×10^{-13} s. Measuring the D_s lifetime assuming no $D^\pm \to \phi \pi^\pm$ production changes the measured value by 0.2×10^{-13} s. Finally, changing our assumption for the lifetime of the $D^\pm$ and D^0 mesons by the errors of the world average produced changes of -0.07×10^{-13} s and $+0.02 \times 10^{-13}$ s.

Adding these contributions in quadrature we arrive at our value for the D_s meson lifetime of:

$$\tau = (5.7^{+3.6}_{-2.6} \pm 0.9) \times 10^{-13}\ \text{s}.$$

This result represents our full data sample and replaces the preliminary value given previously [20]. It may be compared to a recent world average $\tau = (3.5^{+0.6}_{-0.5}) \times 10^{-13}$ s [21].

References

1. TASSO Collab. M. Althoff et al.: Phys. Lett. 136B (1984) 130
2. TASSO Collab. M. Althoff et al.: Z. Phys. C – Particles and Fields 22 (1984) 307
3. TASSO Collab. R. Brandelik et al.: Phys. Lett. 83B (1979) 261; R. Brandelik et al.: Z. Phys. C – Particles and Fields 4 (1980) 87; H. Boerner et al.: Nucl. Instrum. Methods 176 (1980) 151
4. D.M. Binnie et al.: Nucl. Instrum. Methods A228 (1985) 220
5. TASSO Collab. M. Althoff et al.: Phys. Lett. 141B (1984) 264
6. D.H. Saxon: Nucl. Instrum. Methods 234 (1985) 258
7. G.E. Forden, D.H. Saxon: Nucl. Instrum. Methods A248 (1986) 439
8. Particle Data Group: Review of particle properties. Phys. Lett. 170B (1986) 1–350
9. M. Derrick et al.: Phys. Rev. Lett. 53 (1984) 1971
10. R.M. Baltrusaitis et al.: Phys. Rev. Lett. 56 (1986) 2140
11. M. Suzuki: Phys. Lett. 71B (1977) 139; J.D. Bjorken: Phys. Rev. D17 (1978) 171
12. S. Bethke: Z. Phys. C – Particles and Fields 29 (1985) 175
13. S. Bethke: Proc. Int. Symp. on Production and Decay of Heavy Hadrons, Heidelberg 1986, K.R. Schubert, R. Waldi (eds.) (DESY, 1986) p. 65, and HD-PY 86/07
14. C. Peterson et al.: Phys. Rev. D17 (1983) 105
15. D.H. Saxon: Proc. Int. Conf. on High Energy Phys., Bari, p. 899, 1985
16. W. Toki: Note on the D_s meson in review of particle properties. Phys. Lett. 170B (1986) 146
17. TASSO Collab. M. Althoff et al.: Z. Phys. C – Particles and Fields 32 (1986), 343; D.M. Strom: Ph.d. Thesis, University of Wisconsin-Madison (1986), unpublished
18. G.P. Yost: Nucl. Instrum. Methods 224 (1984) 489
19. C. Caso, M.C. Touboul: CERN/EP 85-176 (1985)
20. G.E. Forden: Proc. XXIII Int. Conf. High Energy Phys., Berkeley, 1986; S.C. Loken (ed.). World Scientific. p. 761
21. M.G.D. Gilchriese: Proc. XXIII Int. Conf. High Energy Phys., Berkeley, 1986; S.C. Loken (ed.). World Scientific. p. 140 After completion of this paper we learned about a new measurement of the D_s meson lifetime by the ACCMOR Collaboration, CERN/EP 86-172 (1986)