PHYSICAL REVIEW D **88,** 034034 (2013)

Hadronic and radiative D^* widths

Jonathan L. Rosner*

Enrico Fermi Institute and Department of Physics, University of Chicago, 5620 South Ellis Avenue, Chicago, Illinois 60637, USA
(Received 11 July 2013; published 29 August 2013)

A recent measurement of the total D^{*+} width, $\Gamma_{\rm tot}(D^{*+}) = (83.3 \pm 1.3 \pm 1.4)$ keV, is shown to be close to earlier predictions based on the single-quark-transition hypothesis. Those predictions are updated using more recent masses and branching fractions to a value of 80.4 keV, with a small uncertainty associated with the radiative branching fractions of D^{*0} and D^{*+}. A prediction for the total width of $D_2^*(2460)$ and its partial width into $D^*\pi$ and $D\pi$ is also updated and found to be in agreement with experiment.

DOI: 10.1103/PhysRevD.88.034034 PACS numbers: 14.40.Lb, 13.25.Ft, 12.39.Hg, 12.39.Jh

I. INTRODUCTION

The *BABAR* Collaboration [1,2] has recently measured the natural linewidth of the $D^{*+}(2010)$ vector meson, obtaining the very precise value $\Gamma_{\rm tot}(D^{*+}) = (83.3 \pm 1.3 \pm 1.4)$ keV. The purpose of the present paper is to update old predictions of this width [3–5]. For other early predictions see, e.g., Refs. [6,7]; a later discussion may be found in Ref. [8]. The new value, 80.4 keV, based on recent inputs, is close to the observed one. Predictions of radiative D^* partial widths and of decay properties of the tensor charmed meson $D_2^*(2460)$ are also updated and found to be in agreement with observation.

Predictions for hadronic decays of D^* are treated in Sec. II, while those of radiative D^* decays are discussed in Sec. III. These results are then combined and compared with experiment in Sec. IV. Predictions for decay properties of $D_2^*(2460)$ are updated and compared with experiment in Sec. V, while Sec. VI concludes.

II. HADRONIC D^* DECAYS

The treatment of hadronic decays of the form $M^* \to M\pi$ follows the single-quark-transition formalism introduced by Melosh [9] and applied by Gilman, Kugler, and Meshkov [10,11]. We relate the decays $D^* \to D\pi$ to the well-measured decays $K^*(890) \to K\pi$ using kinematic factors from Ref. [3]. For a meson composed of one light quark (u or d) and one heavy quark (treating s and c both as heavy), one expects

$$\Gamma(M^* \to M\pi) = \frac{p_\pi^3}{M^*} C^2 E_\pi E_M |A|^2, \tag{1}$$

where E_π and E_M are the energies of π and M in the M^* center-of-mass system (cms), C is an isospin Clebsch-Gordan coefficient, and A is an amplitude taken common to $K^* \to K\pi$ and $D^* \to D\pi$.

We take the properties of the decay $K^* \to K\pi$ from Ref. [12]. For the decay width, we ignore small K^* radiative decay rates and take the partial width into $K\pi$ to be the total width. Averaging the values [12] $\Gamma(K^{*\pm}) = 50.8 \pm 0.9$ MeV and $\Gamma(K^{*0}) = 48.7 \pm 0.8$ MeV, we estimate $\Gamma(K^* \to K\pi) = 49.6 \pm 0.6$ MeV. (A slightly higher value of 51.1 ± 1.1 MeV was taken in Ref. [4].) Taking average pion, kaon, and K^* masses, we find $p_\pi = 289$ MeV, $E_\pi = 320$ MeV, $E_K = 574$ MeV, and hence $|A|^2 = 1.00 \times 10^{-8}$ MeV^{-3}.

We now use D and D^* masses from Ref. [12] [consistent within errors with the more precise measurement [1,2] of $M(D^{*+}) - M(D^0) = 145\,425.8 \pm 0.5 \pm 1.8$ keV] to calculate the corresponding quantities for $D^* \to D\pi$ decays. We find $\Gamma(D^{*+} \to D^0\pi^+) = 54.8$ keV, $\Gamma(D^{*+} \to D^+\pi^0) = 24.2$ keV, and $\Gamma(D^{*0} \to D^0\pi^0) = 34.7$ keV. These values are compared with ones obtained in Refs. [3,4] in Table I. Differences are due primarily to slightly different values of p_π and $\Gamma(K^* \to K\pi)$.

III. RADIATIVE D^* DECAYS

The radiative decays $D^* \to D\gamma$ are among a large class of magnetic dipole transitions between ${}^3S_1$ and ${}^1S_0$ states, all of which have been successfully described within a nonrelativistic approach [13,14]. Such M1 transitions from vector mesons M^* to pseudoscalar mesons M composed of quarks $A\bar{B}$ proceed at a rate [15,16]

$$\Gamma(M^* \to M\gamma) = \frac{p_\gamma^3}{3\pi}[\mu_A + \mu_B]^2 |I|^2, \tag{2}$$

where p_γ is the photon momentum in the cms and μ_A and μ_B are the magnetic moments of the quarks, $\mu_A = |e|Q_A/(2m_A)$, with $|e|Q_A$ denoting the charge of quark A. The quantity $I = \langle f|i\rangle$ represents the overlap between initial and final wave functions. $|I|^2$ is found to be about 1/2 for a large class of light-quark transitions [13,14] and for the charmed quark mass $m_c = 1662$ MeV assumed in Ref. [4] gives rise to a prediction $\Gamma(J/\psi \to \eta_c\gamma) = 2.32$ keV. With the observed branching fraction $\mathcal{B}(J/\psi \to \eta_c\gamma) = (1.7 \pm 0.4)\%$ and observed total width $\Gamma_{\rm tot}(J/\psi) = (92.9 \pm 2.8)$ keV [12], this gives an observed $\Gamma(J/\psi \to \eta_c\gamma) = (1.58 \pm 0.37)$ keV, or

*rosner@hep.uchicago.edu

TABLE I. Comparison of predictions for $D^* \to D\pi$ partial widths, in keV.

Decay	Ref. [3] p_π (MeV)	Ref. [3] Γ (KeV)	Ref. [4] p_π (MeV)	Ref. [4] Γ (KeV)	This work p_π (MeV)	This work Γ (KeV)
$D^{*+} \to D^0\pi^+$	38.9	53.4	39.2	56.9	39.3	54.8
$D^{*+} \to D^+\pi^0$	36.6	22.2	38.4	25.9	38.2	24.2
$D^{*0} \to D^0\pi^0$	45.3	43.4	44.1	39.7	42.9	34.7

$|I|^2 = 0.68 \pm 0.16$. A particularly well-determined light-quark radiative decay width, $\Gamma(K^{*0} \to K^0\gamma) = 116.5 \pm 9.9$ keV [17], when compared with the prediction of Eq. (2), gives $|I|^2 = 0.52 \pm 0.04$ for the light-quark masses [13,14] $m_u = m_d = 310$ MeV$/c^2$, $m_s = 485$ MeV$/c^2$. The overlaps $|I|^2 < 1$ may be taken as a proxy for relativistic effects ignored here.

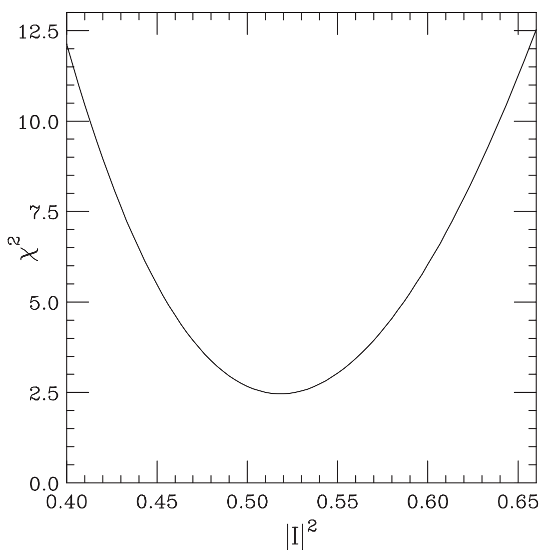

FIG. 1. Dependence of χ^2 for fit to three D^{*+} and two D^{*0} branching fractions on the square $|I|^2$ of the overlap integral describing M1 transitions.

Applying Eq. (2) to radiative D^* decays, we find

$$\Gamma(D^{*+} \to D^+\gamma) = (2.76 \text{ keV})|I|^2, \quad \Gamma(D^{*0} \to D^0\gamma) = (40.8 \text{ keV})|I|^2. \tag{3}$$

The suppression of the charged D^* radiative decay width is due to the partial cancellation of contributions of the charmed and d quarks. This suppression was noted quite early [3,7] and was confirmed experimentally only some time later.

IV. COMPARISON WITH EXPERIMENT

We predict the following total widths for D^{*+} and D^{*0}, parametrized as functions of the square $|I|^2$ of the overlap integral describing M1 radiative transitions:

$$\Gamma_{\text{tot}}(D^{*+}) = (79.0 + 2.76|I|^2) \text{ keV}, \quad \Gamma_{\text{tot}}(D^{*0}) = (34.7 + 40.8|I|^2) \text{ keV}. \tag{4}$$

Using the partial widths predicted in the previous two sections, we may then predict branching fractions as functions of $|I|^2$. They may be compared with the observed branching fractions [12] and a χ^2 formed based on three D^{*+} and two D^{*0} branching fractions. The result is shown in Fig. 1. The minimum $\chi^2 = 2.46$ occurs for $|I|^2 = 0.52$ and is less than one unit above the minimum for a variation of ± 0.04 about this value.

The dependence of the branching fractions for the radiative D^* decays is shown in Fig. 2. The major constraint on $|I|^2$ clearly comes from $\mathcal{B}(D^{*0} \to D^0\gamma)$.

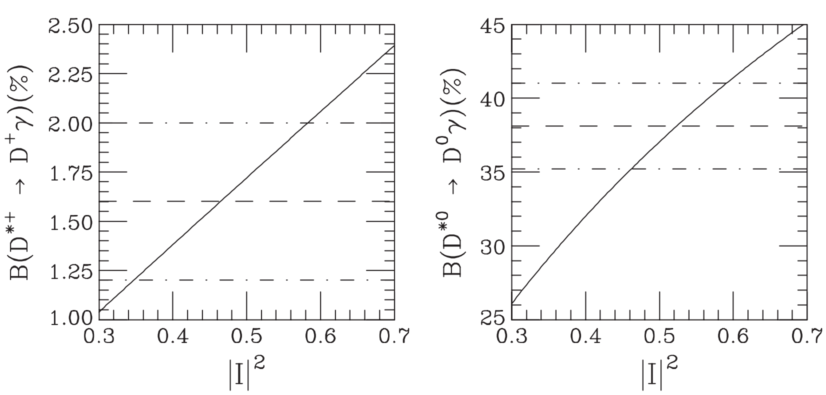

FIG. 2. Dependence of branching fractions for radiative D^* decays on square $|I|^2$ of overlap integral. Horizontal dashed lines denote observed central values of branching fractions [12], with $\pm 1\sigma$ errors denoted by dot-dashed lines.

TABLE II. Comparison of predicted D^* branching fractions and total widths with experiment [12], for $|I|^2 = 0.52 \pm 0.04$.

Quantity	Prediction	Experiment [12][a]
$\mathcal{B}(D^{*+} \to D^0\pi^+)$	$(68.1 \pm 0.1)\%$	$(67.7 \pm 0.5)\%$
$\mathcal{B}(D^{*+} \to D^+\pi^0)$	$(30.1 \pm 0.1)\%$	$(30.7 \pm 0.5)\%$
$\mathcal{B}(D^{*+} \to D^+\gamma)$	$(1.8 \pm 0.2)\%$	$(1.6 \pm 0.4)\%$
$\Gamma_{tot}(D^{*+})$	(80.5 ± 0.1) keV	$(83.3 \pm 1.3 \pm 1.4)$ keV
$\mathcal{B}(D^{*0} \to D^0\pi^0)$	$(62.0 \pm 1.7)\%$	$(61.9 \pm 2.9)\%$
$\mathcal{B}(D^{*0} \to D^0\gamma)$	$(38.0 \pm 1.7)\%$	$(38.1 \pm 2.9)\%$
$\Gamma_{tot}(D^{*0})$	(55.9 ± 1.6) keV	<2.1 MeV

[a]Experimental value of $\Gamma_{tot}(D^{*+})$ from Refs. [1,2].

In Table II we compare our predictions for $|I|^2 = 0.52 \pm 0.04$ with experiment. The agreement is satisfactory. The predicted D^{*0} total width is far below an old upper bound [18] of 2.1 MeV. It would be an interesting experimental challenge to see if some very rare D^{*0} decay with a calculable decay rate could be used to provide indirect information on the D^{*0} total width.

Reference [8] takes into account chiral loops and calculates the total D^{*+} width as a function of $\mathcal{B}(D^{*+} \to D^+\gamma)$. For any given value of this branching ratio, a range of D^{*+} widths is obtained as a result of uncertainties in D^{*0} branching fractions, which amounted to 4.0% at the time. These have now been reduced to 2.9% (see Table II). At the time of Ref. [8] only an upper bound on $\mathcal{B}(D^{*+} \to D^+\gamma)$ of 4.2% was available. With the values in Table II Ref. [8] would now find a range consistent with experiment:

$$64 \text{ keV} \leq \Gamma_{tot}(D^{*+}) \leq 123 \text{ keV}. \tag{5}$$

V. UPDATED PREDICTIONS FOR $D_2^*(2460)$

In Ref. [4] we related D-wave decays of $K_2(1425)$ [now called $K_2(1430)$] to the corresponding D-wave decays of the lowest-lying spin-two charmed meson, assuming its mass was 2420 MeV$/c^2$. This corresponded to a $D^*\pi$ resonance whose spin and parity had not yet been determined. The state now called $D_2^*(2460)$ has a mass which, based on the average of charged and neutral states in Ref. [12], we shall take to be 2462.8 ± 0.7 MeV$/c^2$. Scaling the prediction of [4] to the new D_2 mass, we then find

$$\Gamma(D_2^* \to D\pi) = 27.4 \text{ MeV}, \quad \Gamma(D_2^* \to D^*\pi) = 19.4 \text{ MeV}. \tag{6}$$

Neglecting other possible decays (none are reported in Ref. [12]), we find a total width of 46.8 MeV, to be compared with the observed average of the charged and neutral widths, 48.4 ± 1.4 MeV. The predicted ratio of $D\pi$ to $D^*\pi$ partial widths is 1.41, to be compared to the observed value of 1.56 ± 0.16 [12]. Predictions in this range (under varied assumptions) also have been obtained in Ref. [19].

New data on the $D_2^*(2460)$ not included in the 2012 Particle Data Group average have been reported by the ZEUS Collaboration at HERA [20]:

$$\Gamma(D_2^{*0}) = (46.6 \pm 8.1^{+5.9}_{-3.8}) \text{ MeV}, \tag{7}$$

$$\frac{\mathcal{B}(D_2^{*0} \to D^+\pi^-)}{\mathcal{B}(D_2^{*0} \to D^{*+}\pi^-)} = 1.4 \pm 0.3 \pm 0.3, \tag{8}$$

$$\frac{\mathcal{B}(D_2^{*+} \to D\pi)}{\mathcal{B}(D_2^{*+} \to D^*\pi)} = 1.1 \pm 0.4^{+0.3}_{-0.2}. \tag{9}$$

These results are also in accord with our predictions.

VI. CONCLUSIONS

Experimental results continue to confirm some very early predictions of charmed meson hadronic and radiative decays. These predictions lie within the scope of heavy quark effective theory but antedate it by a considerable amount. The refinement of Ref. [8], incorporating contributions of chiral loops, also leads to predictions in accord with experiment.

ACKNOWLEDGMENTS

I thank Uri Karshon for a helpful communication. This work was supported in part by the United States Department of Energy under Grant No. DE FG02 90ER40560.

[1] J. P. Lees *et al.* (*BABAR* Collaboration), arXiv:1304.5009.
[2] J. P. Lees *et al.* (*BABAR* Collaboration), arXiv:1304.5657.
[3] E. Eichten, K. Gottfried, T. Kinoshita, K. D. Lane, and T.-M. Yan, Phys. Rev. D **21**, 203 (1980).
[4] J. L. Rosner, Comments Nucl. Part. Phys. **16**, 109 (1986).
[5] J. L. Rosner, in *Particles and Fields 3, Proceedings of the Banff Summer Institute (Banff, Canada, 1988)*, edited by A. N. Kamal and F. C. Khanna (World Scientific, Singapore, 1989), p. 395.
[6] S. Godfrey and N. Isgur, Phys. Rev. D **32**, 189 (1985).
[7] R. L. Thews and A. N. Kamal, Phys. Rev. D **32**, 810 (1985).
[8] J. F. Amundson, C. G. Boyd, E. E. Jenkins, M. E. Luke, A. V. Manohar, J. L. Rosner, M. J. Savage, and M. B. Wise, Phys. Lett. B **296**, 415 (1992).

[9] H. J. Melosh, Phys. Rev. D **9**, 1095 (1974).
[10] F. J. Gilman, M. Kugler, and S. Meshkov, Phys. Lett. **45B**, 481 (1973).
[11] F. J. Gilman, M. Kugler, and S. Meshkov, Phys. Rev. D **9**, 715 (1974).
[12] J. Beringer *et al.* (Particle Data Group), Phys. Rev. D **86**, 010001 (2012).
[13] J. L. Rosner, in *Techniques and Concepts of High-Energy Physics*, edited by T. Ferbel (Plenum, New York, 1981); NATO Adv. Study Inst. Ser., Ser. B **66**, 1 (1981).
[14] S. Gasiorowicz and J. L. Rosner, Am. J. Phys. **49**, 954 (1981).
[15] J. D. Jackson, Lawrence Berkeley Laboratory Report No. LBL-5500, reprinted in Proceedings of the SLAC Summer Institute on Particle Physics, 1976, SLAC Report No. SLAC-198, edited by Martha C. Zipf, p. 147.
[16] E. Eichten, K. Gottfried, T. Kinoshita, K. D. Lane, and T.-M. Yan, Phys. Rev. D **17**, 3090 (1978); **21**, 313 (1980).
[17] D. Carlsmith *et al.*, Phys. Rev. Lett. **56**, 18 (1986).
[18] S. Abachi *et al.* (HRS Collaboration), Phys. Lett. B **212**, 533 (1988).
[19] S. Godfrey and R. Kokoski, Phys. Rev. D **43**, 1679 (1991).
[20] H. Abramowicz *et al.* (ZEUS Collaboration), Nucl. Phys. **B866**, 229 (2013).