PROCEEDINGS OF SCIENCE

$D^+ \to \mu^+\nu$ and f_{D^+} from 281 pb^{-1} at ψ(3770) from CLEO-c

Yongsheng Gao (for CLEO Collaboration)*

Southern Methodist University, Dallas, Texas 75275-0175, USA

E-mail: gao@mail.physics.smu.edu

We report improved measurements of branching fraction and decay constant f_{D^+} in $D^+ \to \mu^+\nu$ using 281 pb^{-1} of data taken on the $\psi(3770)$ resonance with the CLEO-c detector. We extract a relatively precise value for the decay constant of the D^+ meson by measuring $\mathscr{B}(D^+ \to \mu^+\nu) = (4.40 \pm 0.66^{+0.09}_{-0.12}) \times 10^{-4}$ and find $f_{D^+} = (222.6 \pm 16.7^{+2.8}_{-3.4})$ MeV. We also set a 90% confidence upper limit on $\mathscr{B}(D^+ \to e^+\nu) < 2.4 \times 10^{-5}$ which limits contributions from non-standard model physics.

International Europhysics Conference on High Energy Physics
July 21st - 27th 2005
Lisboa, Portugal

*Speaker.

1. Introduction

The last 3 decades have witnessed amazing progress in Heavy Flavor physics. To test the SM and search for new physics, the precise measurements of CKM matrix elements have been one of the focus of current HEP efforts. However, our discovery potential is limited by our ability to relate the world of hadrons to the world of quarks, that is, the systematic errors due to non-pertubative QCD.

The CLEO-c program at $\psi(3770)$ is an important part of the global efforts in heavy flavor physics. The precise measurements of decay constants f_{D^+} and f_{D_s} will test the Lattice QCD calculation and gain confidence in the theoretical prediction of f_B. The decay $D^+ \to \ell^+\nu$ proceeds by the c and $\overline{d}$ quarks annihilating into a virtual W^+, with a decay width [1]

$$\Gamma(D^+ \to \ell^+\nu) = \frac{G_F^2}{8\pi} f_{D^+}^2 m_\ell^2 M_{D^+} \left(1 - \frac{m_\ell^2}{M_{D^+}^2}\right)^2 |V_{cd}|^2 \quad , \tag{1.1}$$

where M_{D^+} is the D^+ mass, m_ℓ is the mass of the final state lepton, $|V_{cd}|$ is a CKM matrix element that we assume to be equal to $|V_{us}|$, and G_F is the Fermi coupling constant.

2. Data Sample and Event Selection

In this study [2] we use 281 pb^{-1} of data produced in e^+e^- collisions using the Cornell Electron Storage Ring (CESR) and recorded at the ψ'' resonance (3.770 GeV). Our analysis strategy is to fully reconstruct the D^- meson in one of six decay modes listed in Table 1 and search for a $D^+ \to \mu^+\nu$ decay in the rest of the event. Track selection, particle identification (PID), π^0, K_S, and muon selection cuts are identical to those used in Ref. [3].

Table 1 gives the numbers of signal and background events for each mode within the signal region, defined as $m_D - 2.5\,\sigma_{m_{BC}} < m_{BC} < m_D + 2.0\,\sigma_{m_{BC}}$, where $\sigma_{m_{BC}}$ is the r.m.s. width of the lower side of the distribution.

Mode	Signal	Background
$K^+\pi^-\pi^-$	77387 ± 281	1868
$K^+\pi^-\pi^-\pi^0$	24850 ± 214	12825
$K_S\pi^-$	11162 ± 136	514
$K_S\pi^-\pi^-\pi^+$	18176 ± 255	8976
$K_S\pi^-\pi^0$	20244 ± 170	5223
$K^+K^-\pi^-$	6535 ± 95	1271
Sum	158354 ± 496	30677

Table 1: Tagging modes and numbers of signal and background events.

Using our sample of D^- candidates we search for events with a single additional charged track presumed to be a μ^+. The track must make an angle >35.9° with respect to the beam-line, deposit less than 300 MeV of energy in the calorimeter, characteristic of a minimum ionizing particle, and

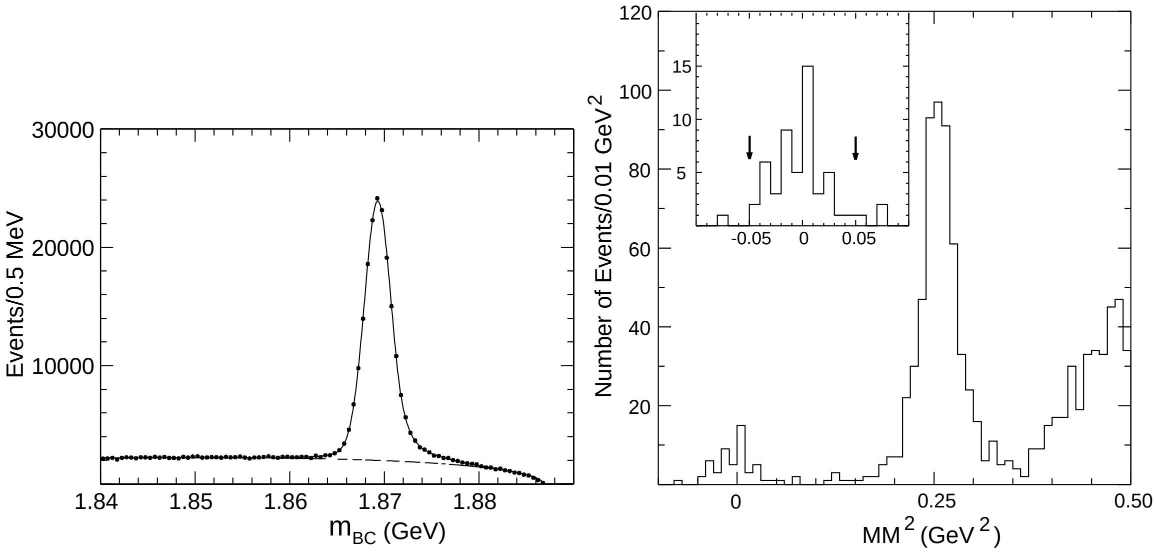

Figure 1: Left: Beam-constrained mass for the sum of fully reconstructed D^- decay candidates. The solid curve shows the fit to the sum of signal and background functions, while the dashed curve indicates the background. Right: MM^2 using D^- tags and one additional opposite sign charged track and no extra energetic clusters (see text). The insert shows the signal region for $D^+ \to \mu^+\nu$ enlarged; the defined signal region is shown between the two arrows.

not be identified as a kaon. Then we infer the existence of the neutrino by requiring a measured value near zero (the ν mass squared) of the missing mass squared defined as

$$\mathrm{MM}^2 = \left(E_{\mathrm{beam}} - E_{\mu^+}\right)^2 - \left(-\boldsymbol{p}_{D^-} - \boldsymbol{p}_{\mu^+}\right)^2, \qquad (2.1)$$

where $\boldsymbol{p}_{D^-}$ is the three-momentum of the fully reconstructed D^-.

In order to restrict the sample to candidate $\mu^+\nu$ events, we select events with only one charged track in addition to the tagging D^-. Events with extra tracks originating within 0.5 m (radially) of the event vertex are rejected, as are events having a maximum neutral energy cluster of more than 250 MeV. These cuts are highly effective in reducing backgrounds especially from $D^+ \to \pi^+\pi^0$ decays, but they introduce an inefficiency because the decay products of the tagging D^- can interact in the detector material leaving spurious tracks or clusters.

3. Results

The MM^2 distribution is shown in Fig. 1. We see a peak near zero containing 50 events within the interval -0.050 GeV^2 to +0.050 GeV^2, approximately $\pm 2\sigma$ wide. The peak is mostly due to $D^+ \to \mu^+\nu$ signal. The large peak centered near 0.25 GeV^2 is from the decay $D^+ \to \overline{K}^0\pi^+$ that is far from our signal region and is expected, since many K_L escape our detector.

There are several potential background sources; these include other D^+ modes, misidentified $D^0\overline{D}^0$ events, and continuum including $e^+e^- \to \gamma\psi'$. Hadronic sources need to be considered because the requirement of the muon depositing less than 300 MeV in the calorimeter, while about 99% efficient on muons, rejects only about 40% of pions or kaons as determined from a pure sample of $D^0 \to K^-\pi^+$ decays.

There are a few specific D^+ decay modes that contribute unwanted events in the signal region. Residual $\pi^+\pi^0$ background is determined from a simulation that uses a branching fraction of (0.13±0.02)% [4] and yields 1.40±0.18±0.22 events; the first error is due to Monte Carlo statistics, and the second is systematic, due mostly to the branching ratio uncertainty. We find background from $D^+ \to \tau^+\nu$ only when $\tau^+ \to \pi^+\nu$. Since the $\tau^+\nu$ branching ratio is known to be 2.65 times the $\mu^+\nu$ rate from Eq. 1.1, our simulation gives 1.08±0.15±0.16 events, where the systematic error arises from our final uncertainty on the $\mu^+\nu$ decay rate. The $\overline{K}^o\pi^+$ mode (branching ratio of (2.77±0.18)% [5]) gives a large peak in the MM^2 spectrum near 0.25 GeV^2. While far from our signal region, the tail of the distribution can contribute. Our total background is 2.81±0.30±0.27 events. The backgrounds from other D^+, D^0, and continuum sources are limited to less than 0.4, 0.4, and 1.2 events at 90% confidence level (C.L.), respectively. To account for possible backgrounds from these sources, we add them as 32% C.L. (1σ) values in quadrature for a positive error and therefore add an additional $^{+0.8}_{-0}$ event systematic error.

We have $47.2\pm7.1^{+0.3}_{-0.8}$ $\mu^+\nu$ signal events after subtracting background. The detection efficiency for the single muon of 69.4% includes the selection on MM^2 within $\pm2\sigma$ limits, the tracking, the particle identification, probability of the crystal energy being less than 300 MeV, and corrections for final state radiation. It does not include the 96.1% efficiency of not having another unmatched cluster in the event with energy greater than 250 MeV. We also need to account for the fact that it is easier to find tags in $\mu^+\nu$ events than in generic decays by a small amount, (1.5±0.4±0.5)%, as determined by Monte Carlo simulation.

Our result for the branching fraction, using the tag sum in Table 1, is

$$\mathscr{B}(D^+ \to \mu^+\nu) = (4.40 \pm 0.66^{+0.09}_{-0.12}) \times 10^{-4} \ . \tag{3.1}$$

The decay constant f_{D^+} is then obtained from Eq. (1.1) using 1.040±0.007 ps as the D^+ lifetime [5], and $|V_{cd}| = 0.2238\pm0.0029$ [6]. (We add these two small additional sources of uncertainty into the systematic error.) Our final result is

$$f_{D^+} = (222.6 \pm 16.7^{+2.8}_{-3.4}) \text{ MeV} \ . \tag{3.2}$$

We use the same tag sample to search for $D^+ \to e^+\nu_e$. We identify the electron using a match between the momentum measurement in the tracking system and the energy deposited in the CsI calorimeter as well as insuring that the shape of the energy distribution among the crystals is consistent with that expected for an electromagnetic shower. Other cuts remain the same. We do not find any candidates, yielding a 90% C.L. limit of $\mathscr{B}(D^+ \to e^+\nu_e) < 2.4 \times 10^{-5}$.

4. Conclusions

Our measurement of f_{D^+} is much more precise than previous observations or limits [3, 7]. The theoretical predictions listed in Table 2 were made prior to this result. The first entry is the result from the Fermilab-MILC-HPQCD collaboration that is done with all three light quark flavors unquenched, hence n_f=2+1 [8]. It is about 10% smaller than our result, albeit within error.

The models generally predict $f_{D_S^+}$ to be 10–25% larger than f_{D^+} which is consistent with a previous CLEO measurement [9]. Some non-standard models predict significant rates for the helicity suppressed decay $D^+ \to e^+\nu$ [10]. Our upper limit restricts these models.

Model	f_{D^+} (MeV)	$f_{D_S^+}/f_{D^+}$
hline Lattice (n_f=2+1) [8]	$205 \pm 3 \pm 17$	$1.24 \pm 0.01 \pm 0.07$
QL (Taiwan) [11]	$235 \pm 8 \pm 14$	$1.13 \pm 0.03 \pm 0.05$
QL (UKQCD) [12]	$210 \pm 10^{+17}_{-16}$	$1.13 \pm 0.02^{+0.04}_{-0.02}$
QL [13]	$211 \pm 14^{+0}_{-12}$	1.10 ± 0.02
QCD Sum Rules [14]	203 ± 20	1.15 ± 0.04
QCD Sum Rules [15]	195 ± 20	
Quark Model [16]	243 ± 25	1.10
Potential Model [17]	238	1.01
Isospin Splittings [18]	262 ± 29	

Table 2: Theoretical predictions of f_{D^+} and $f_{D_S^+}/f_{D^+}$. QL indicates quenched lattice calculations.

References

[1] D. Silverman and H. Yao, Phys. Rev. D **38**, 214 (1988).

[2] M. Artuso *et al.* (CLEO), CLNS 05/1932, CLEO 05-20, hep-ex/0508057, submitted to Phys. Rev. Lett.

[3] G. Bonvicini *et al.* (CLEO), Phys. Rev. D **70**, 112004 (2004).

[4] K. Arms *et al.* (CLEO), Phys. Rev. D **69**, 071102 (2004).

[5] S. Eidelman *et al.*, Phys. Lett. B **592**, 1 (2004).

[6] We assume that $|V_{cd}|$ equals $|V_{us}|$ and use the average given by Nierste, "Quark mixing and CP violation - the CKM matrix," Lepton-Photon Symposium, Uppsala, Sweden, (2005).

[7] J. Adler *et al.* (Mark III), Phys. Rev. Lett. **60**, 1375 (1988); erratum-ibid, **63**, 1658 (1989); J. Z. Bai *et al.* (BES), Phys. Lett. B **429**, 188 (1998); M. Ablikim *et al.* (BES), Phys. Lett. B **610**, 183 (2005).

[8] C. Aubin *et al.* (MILC), "Charm meson decay constants in three-flavor lattice QCD," [hep-lat/0506030] (2005).

[9] M. Chadha *et al.* (CLEO), Phys. Rev. D **58**, 032002 (1998).

[10] See for example A. G. Akeroyd and S. Recksiegel, Phys. Lett. B **554**, 38 (2003).

[11] T. W. Chiu *et al.*, "Pseudoscalar Decay Constants f_D and f_{D_S} in Lattice QCD with Exact Chiral Symmetry," [hep-ph/0506266] (2005) .

[12] L. Lellouch and C.-J. Lin (UKQCD), Phys. Rev. D **64**, 094501 (2001).

[13] D. Becirevic *et al.*, Phys. Rev. D **60**, 074501 (1999).

[14] S. Narison, "Light and Heavy Quark Masses, Flavour Breaking of Chiral Condensates, Meson Weak Leptonic Decay Constants in QCD," [hep-ph/0202200] (2002).

[15] A. Penin and M. Steinhauser, Phys. Rev. D **65**, 054006 (2002).

[16] D. Ebert *et al.*, Mod. Phys. Lett. **A17**, 803 (2002).

[17] Z. G. Wang *et al.*, Nucl. Phys. **A744**, 156 (2004); L. Salcedo *et al.*, Braz. J. Phys. **34**, 297 (2004).

[18] J. Amundson *et al.*, Phys. Rev. D **47**, 3059 (1993).