CLNS 97/1460
CLEO 97-1

Studies of the Cabbibo-suppressed decays $D^+ \to \pi^0 \ell^+ \nu$ and $D^+ \to \eta e^+ \nu_e$

CLEO Collaboration

(March 25, 1997)

Abstract

Using 4.8 fb^{-1} of data taken with the CLEO II detector, the branching fraction for the Cabibbo suppressed decay $D^+ \to \pi^0 \ell^+ \nu$ measured relative to the Cabibbo favored decay $D^+ \to \overline{K^0} \ell^+ \nu$ is found to be $0.046 \pm 0.014 \pm 0.017$. Using V_{cs} and V_{cd} from unitarity constraints, we determine $|f_+^\pi(0)/f_+^K(0)|^2 = 0.9 \pm 0.3 \pm 0.3$ We also present a 90% confidence level upper limit for the branching ratio of the decay $D^+ \to \eta e^+ \nu_e$ relative to that for $D^+ \to \pi^0 e^+ \nu_e$ of 1.5.

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Interpretation of semileptonic decays of charm mesons is theoretically straightforward. Amplitudes of decay modes are proportional to the CKM matrix elements and the form factors describing the strong interactions between the final state quarks. In this paper we study the Cabibbo suppressed decays $D^+ \to \pi^0 \ell^+ \nu$ and $D^+ \to \eta \ell^+ \nu$ by measuring the ratios $R_\pi = B(D^+ \to \pi^0 \ell^+ \nu)/B(D^+ \to \overline{K^0} \ell^+ \nu)$ and $R_\eta = B(D^+ \to \eta \ell^+ \nu)/B(D^+ \to \pi^0 \ell^+ \nu)$. Throughout this paper charge conjugate states are implied.

The ratio R_π is proportional to the product $|f_+^\pi(0)/f_+^K(0)|^2 |V_{cd}/V_{cs}|^2$ where $f_+^P(q^2)$ is the hadronic form factor for the decay into the pseudoscalar P. Since unitarity constraints on the Cabibbo-Kobayashi-Maskawa (CKM) matrix [1] yield V_{cd} and V_{cs} with good precision, measurements of R_π and R_η mainly provide constraints on the form factor ratios $|f_+^\pi(0)/f_+^K(0)|$ and $|f_+^\eta(0)/f_+^\pi(0)|$. Model predictions [2] for the first form factor ratio range from 0.7 to 1.4. This range demonstrates the difficulty in predicting how the D meson will couple to the light quark combinations. Assuming a monopole form [3] for the q^2 dependence of the form factor, the decay rate for the decay $D^+ \to P \ell^+ \nu$ can be written as

$$\Gamma = c_1^2 |V_{cd}|^2 |f_+^P(0)|^2 \int \frac{p_P^3}{(1 - \frac{q^2}{M^*})^2} dq^2, \qquad (1)$$

where q^2 is the hadronic four momentum transfer. The mass of the nearest vector pole is $M^* = M_{D^*}$ for $D^+ \to \pi^0 \ell \nu$ and $D^+ \to \eta \ell \nu$, and $M^* = M_{D_s^*}$ for $D^+ \to \overline{K^0} \ell \nu$. The factor c_1^2 accounts for the $d\overline{q}$ content of the final state meson P, and is 1/2 for the π^0 and η modes ($d\overline{d}$), and 1 for the $\overline{K^0}$ mode ($d\overline{s}$). There are several models that predict these rates [4,5]. Using the framework of Heavy Quark Effective Theory and symmetry arguments, measured form factors from semileptonic charm decays can be compared to those for the appropriate $b \to u$ decays [6] used to extract $|V_{ub}/V_{cb}|$.

While the Cabibbo-favored modes in charm semileptonic decay have been well measured [1,7], there are relatively few measurements of Cabibbo-suppressed semileptonic decays. Previous CLEO results for the ratio R_π [8] are based on a total luminosity of 2.1 fb^{-1}, and are superceded by the results presented in this paper. The ratio of branching fractions $R_- = B(D^0 \to \pi^- \ell^+ \nu)/B(D^0 \to K^- \ell^+ \nu)$ is related to R_π by isospin ($R_\pi = 0.5 R_-$). Mark III [9], Fermilab E687 [10], and CLEO [11] have reported results for $B(D^0 \to \pi^- \ell^+ \nu)$ giving a current world average for $R_- = 0.102^{+0.017}_{-0.016}$.

The data sample used for this analysis was recorded with the CLEO-II detector [12] operating at the CESR storage ring at Cornell University. A total luminosity of 4.8 fb^{-1} of e^+e^- collisions was recorded at the $\Upsilon(4S)$ resonance and in the continuum nearby.

In D^+ decays, the combinatoric background can be suppressed by requiring that the D^+ be produced in the decay chain $D^{*+} \to D^+ \pi^0$. The CLEO-II detector, with its excellent photon detection efficiency, is ideally suited for detecting the neutral pions from this decay. Because the final state neutrino is not detected in semileptonic decays, we define $\delta m = M_{\pi_S^0 h_F \ell^+} - M_{h_F \ell^+}$, where h_F refers to the D^+ daughter meson, the "fast" π^0 (π_F^0), the $\overline{K^0}$, or the η. The π_S^0 refers to the "slow" π^0 from the D^{*+}, which is constrained by the production and decay kinematics to have a momentum less than 0.4 GeV/c. While the peak in δm is not as narrow as the peak in fully reconstructed hadronic D^+ decays, a definite peak remains. The width of the peak in this distribution increases as more energy is carried by the neutrino. We therefore limit the neutrino energy by requiring $1.4 \leq M_{h_F \ell^+} < 1.8$ GeV/c^2.

Electrons with momenta above 0.7 GeV/c are identified by requiring that the ratio of the energy (E) deposited in the CsI calorimeter and the momentum (p) measured in the tracking system, E/p, be close to unity and that the energy loss measured by the tracking system be consistent with the electron hypothesis. Muons with momenta above 1.4 GeV/c are identified by their ability to penetrate five nuclear interaction lengths. Electrons (muons) within the fiducial volume are identified with an efficiency of 94% (93%). The probability of a hadron being misidentified as a lepton is $(0.20 \pm 0.06)\%$ for electrons and $(1.4 \pm 0.2)\%$ for muons. We require the leptons to be found in the central region of the detector, where the resolution is best and the acceptance well-understood.

Isolated photons detected by the CsI calorimeter with a minimum energy of 30 MeV are paired to form π^0 and η candidates. For the slow pion, the $\gamma\gamma$ mass is constrained to be within 2.5 standard deviations (about 12.5 MeV/c^2) of the nominal π^0 mass. For the fast π^0 (η), the reconstructed mass is required to be within the range 0.105-0.165 GeV/c^2 (0.510-0.585 GeV/c^2). The decay channel $\eta \to \pi^+\pi^-\pi^0$ was not considered because of its low reconstruction efficiency. For the normalizing $D^+ \to \overline{K^0}\ell^+\nu$ mode, we identify the $\overline{K^0}$ through the $\pi^+\pi^-$ decay of its K_S component. We require the $\pi^+\pi^-$ pair to form a secondary vertex of the correct mass that is displaced at least four standard deviations from the primary vertex.

Combinatoric backgrounds are reduced by several means. We impose the kinematic criteria $0.175 \leq p_{\pi^0_S} < 0.350$ GeV/c, $p_{h_F} \geq 0.7$ GeV/c, and $|\vec{p}_{h_F} + \vec{p}_\ell| \geq 2.1$ GeV/c. Backgrounds from B meson decay are reduced by requiring that the ratio of Fox-Wolfram moments [13] $R_2 = H_2/H_0$ satisfy $R_2 \geq 0.2$. Finally, we consider only well-measured tracks and events with a hadronic event structure.

Backgrounds can be divided into four classes: fake slow pions (fake D^*s), fake fast hadrons, fake leptons, and uncorrelated fast-hadron, lepton pairs (fake D^+s). The major contribution to the fake D^+ background in the $D^+ \to \pi^0\ell^+\nu$ channel comes from feed-down from $D^+ \to \overline{K^0}\ell^+\nu$, $\overline{K^0} \to \pi^0\pi^0$. We can correct for this background knowing only the ratio of the reconstruction efficiency for $D^+ \to \pi^0\ell^+\nu$ to the efficiency to reconstruct $D^+ \to \overline{K^0}\ell^+\nu$, $\overline{K^0} \to \pi^0\pi^0$ as $\pi^0\ell^+\nu$, which we determine from Monte Carlo simulation. Monte Carlo studies indicated that the feedthrough from other semileptonic charm decays and from $B\overline{B}$ events is negligible. The other background components were determined from fits to the data.

We fitted the two dimensional distribution of δm versus fast hadron mass to extract the signal yield. Figure 1 shows the distributions for the signal Monte Carlo and data for the $D^+ \to \pi^0 e^+\nu_e$ mode. Figure 2 shows the δm projection for the π^0, $\overline{K^0}$, and η modes. Figure 3 shows the fast hadron mass distributions. The fits used a parametrization of the fast hadron mass obtained by fitting these one-dimensional projections. The signal shape in δm was determined from fits to the distributions of reconstructed signal Monte Carlo. The fake lepton background was determined by performing a fit to the distributions of events which satisfied all requirements except for the lepton identification requirement. The signal yields from these fits were then scaled by the measured misidentification probabilities and subtracted from the yields from the fit to the data. The parameterization of the fake D^* background in δm was determined by looking at a sample of data events whose fast hadron mass was more than 4 sigma from the nominal mass. The signal yields, fake lepton yields, and signal reconstruction efficiencies are presented in Table I. The efficiencies were determined from fits to the distributions from samples of reconstructed signal Monte Carlo.

With the results from the fits given in Table I, we proceed to calculate the ratio of branching fractions $R_\pi = [B(D^+ \to \pi^0 \ell^+ \nu)]/[B(D^+ \to \overline{K^0} \ell^+ \nu)]$. For each leptonic mode we define,

$$R_\pi = \frac{N(\pi^0_F \ell^+ \nu)}{N(K^0_S \ell^+ \nu)} \frac{\epsilon_{\overline{K^0}\ell^+\nu}(\overline{K^0}\ell^+\nu)}{\epsilon(\pi^0 \ell^+ \nu)} - \frac{\epsilon_{\overline{K^0}\ell^+\nu}(\pi^0 \ell^+ \nu)}{\epsilon(\pi^0 \ell^+ \nu)}$$

Here $N(\pi^0_F \ell^+ \nu)$ and $N(K^0_S \ell^+ \nu)$ are the two signal yields after background subtraction, $\epsilon(\pi^0 \ell^+ \nu)$ is the efficiency for a $\pi^0 \ell^+ \nu$ decay to be reconstructed as itself, $\epsilon_{\overline{K^0}\ell^+\nu}(\overline{K^0}\ell^+\nu)$ is the efficiency for a $\overline{K^0}\ell^+\nu$ decay to be reconstructed as $\overline{K^0}\ell^+\nu$, and $\epsilon_{\overline{K^0}\ell^+\nu}(\pi^0 \ell^+ \nu)$ is the efficiency for a $\overline{K^0}\ell^+\nu$ decay to be reconstructed as $\pi^0 \ell^+ \nu$. The ratio for electrons was found to be $R_\pi = (4.5 \pm 1.6 \pm 1.9)\%$, where the first error is statistical and the second is systematic. The ratio for muons was found to be $R_\pi = (4.8 \pm 3.1 \pm 3.2)\%$. Here the error from fake muon subtraction is substantial and the detection efficiency is lower than for the electron channel. We combine the results weighted by their errors to find $R_\pi = (4.6 \pm 1.4 \pm 1.7)\%$.

Most of the systematic effects cancel in the ratio of branching fractions because we impose similar requirements on both the signal and normalization modes. The systematic error for the electron channel is dominated by the parameterizations of the shapes in the δm distribution (30%). This error is correlated between the $\pi^0 e^+ \nu_e$ and $\overline{K^0} e^+ \nu_e$ channels. The systematic error in the ratio due to Monte Carlo simulations of $K^0_S \to \pi^+\pi^-$ and $\pi^0_F \to \gamma\gamma$ is conservatively placed at 10%. Other systematic errors for the electron channel include: statistical error on efficiency fits from Monte Carlo samples (7%), fake lepton subtraction (7%), $D^+ \to \overline{K^0} e^+ \nu_e$ feeddown (9%), other semileptonic charm decay feeddown (16%), and $B\overline{B}$ feeddown (13%). The systematic errors are added in quadrature to obtain a total systematic error in the ratio for electrons of 41%.

The fit to the $D^+ \to \eta e^+ \nu$ channel yielded 6 ± 8 events. We did not consider the muon channel due to the low detection efficiency. To obtain an upper limit on R_η, we scale this yield by the reconstruction efficiency of $(0.26 \pm 0.02)\%$, and normalize to the average $D^+ \to \pi^0 \ell^+ \nu$ yield of $(4.39 \pm 2.22) \times 10^3$ events. The latter was estimated from our R_π measurement and the average of the efficiency-corrected yields for $D^+ \to \overline{K^0}\ell^+\nu$ in the electron and muon channels. We find $R_\eta = \frac{B(D^+ \to \eta \ell^+ \nu)}{B(D^+ \to \pi^0 \ell^+ \nu)} =< 1.5.$ at the 90% confidence level. This result is dominated by statistical error, but includes a 30% systematic error that was combined in quadrature with the statistical error.

We have measured the branching fraction of the Cabibbo suppressed decay $D^+ \to \pi^0 \ell^+ \nu$ relative to $D^+ \to \overline{K^0}\ell^+\nu$. Using our measurement of this ratio, we find using Equation (1) $|f^\pi_+(0)/f^K_+(0)|^2 |V_{cd}/V_{cs}|^2 = 0.046 \pm 0.014 \pm 0.017$. The integral in Equation (1) times the constant term is approximately 1 here. Unitarity constraints on the CKM matrix yield $|V_{cd}/V_{cs}|^2 = 0.051 \pm 0.001$ [1] which translates to a value of $0.9 \pm 0.3 \pm 0.3$ for $|f^\pi_+(0)/f^K_+(0)|^2$. Model predictions [2] are in agreement with our measurement. We can combine our measurement of R_π with the measurements of $0.5 \times R_-$ to obtain $R_\pi = 0.050 \pm 0.008$ and $|f^\pi_+(0)/f^K_+(0)| = 0.99 \pm 0.08$. The upper limit on the ratio R_η is consistent with current predictions.

We gratefully acknowledge the effort of the CESR staff in providing us with excellent luminosity and running conditions. J.P.A., J.R.P., and I.P.J.S. thank the NYI program of the NSF, M.S. thanks the PFF program of the NSF, G.E. thanks the Heisenberg Foundation,

TABLE I. Results of fits to the M_{h_F} versus δm distributions for each of the three analyses.

Sample	$\pi^0\ell^+\nu$		$\overline{K^0}\ell^+\nu$	
	Electrons	Muons	Electrons	Muons
Data	75 ± 15	83 ± 18	530 ± 29	178 ± 17
Fake Lepton	10 ± 3	48 ± 10	7 ± 2	25 ± 5
SUBTRACTED	$65 \pm 15 \pm 20$	$35 \pm 18 \pm 16$	$523 \pm 29 \pm 38$	$153 \pm 17 \pm 13$
$\epsilon(\pi^0\ell^+\nu$ MC)%	$1.01 \pm 0.05 \pm 0.03$	$0.66 \pm 0.05 \pm 0.01$	-	-
$\epsilon(\overline{K^0}\ell^+\nu$ MC)%	0.020 ± 0.004	0.007 ± 0.005	$0.54 \pm 0.01 \pm 0.02$	$0.17 \pm 0.02 \pm 0.01$
$\epsilon(\overline{K^{*0}}\ell^+\nu$ MC)%	< 0.001	< 0.001	< 0.001	< 0.001
YIELD ($\times 10^3$)	$6.44 \pm 1.49 \pm 2.00$	$5.30 \pm 2.73 \pm 2.84$	$96.85 \pm 5.37 \pm 7.95$	$90.00 \pm 10.00 \pm 13.66$

K.K.G., M.S., H.N.N., T.S., and H.Y. thank the OJI program of DOE, J.R.P., K.H., M.S. and V.S. thank the A.P. Sloan Foundation, and A.W. and R.W. thank the Alexander von Humboldt Stiftung for support. M.S. is supported as a Cottrell Scholar of Research Corporation. This work was supported by the National Science Foundation, the U.S. Department of Energy, and the Natural Sciences and Engineering Research Council of Canada.

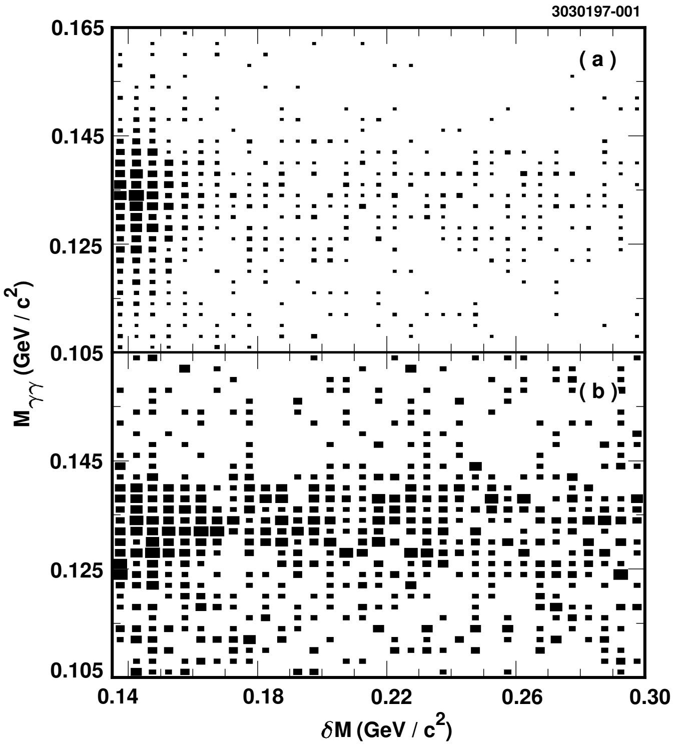

FIG. 1. The distribution of $M_{\gamma\gamma}$ versus δm for a) $D^+ \to \pi^0 e^+ \nu$ Monte Carlo events and b) data.

REFERENCES

[1] R.M. Barnett *et al.* (Particle Data Group), Phys. Rev. **D54**, 1 (1996).

[2] S. Narison *et al.*, Phys. Lett. **B377**, 163 (1994); V. Lubicz *et al.*, Phys. Lett. **B274**, 415 (1992); M. Bauer, B. Stech, M. Wirbel, Z. Phys. **C34**, 103 (1987); C.A. Domingues, Phys. Lett. **B207**, 499 (1988); M. Crisafulli *et al.*, Phys. Lett. **B223**, 90 (1989); G.P. Lepage and S.J. Brodsky, Phys. Rev. **D22**, 2157 (1980).

[3] A. Ali and T.C. Yang, Phys. Lett. **B65**, 275 (1976).

[4] J.G. Körner, K. Schilcher, M. Wirbel, and Y.L. Wu, Z. Phys. **C38**, 511 (1988).

[5] N. Isgur and D. Scora, Phys. Rev. **D52**, 2783 (1995); see also N. Isgur *et al.*, Phys. Rev. **D39**, 799 (1989).

[6] N. Isgur and M.B. Wise, Phys. Lett. **B232**, 113 (1989); N. Isgur and M.B. Wise, Phys. Rev. **D42**, 2388 (1990).

[7] A. Bean *et al.*, Phys. Lett. **B317**, 647 (1993).

[8] M.S. Alam *et al.*, Phys. Rev. Lett. **71**, 1311 (1993).

[9] J. Adler *et al.*, Phys. Rev. Lett. **62**, 1821 (1989).

[10] P.L. Frabetti *et al.*, Phys. Lett. **B382**, 312 (1996).

[11] F. Butler *et al.*, Phys. Rev. **D52**, 2656 (1995).

[12] Y. Kubota *et al.*, Nucl. Intr. and Meth. **A320**, 66 (1992).

[13] G.C. Fox and S. Wolfram, Phys. Rev. Lett. **41**, 1581 (1978).

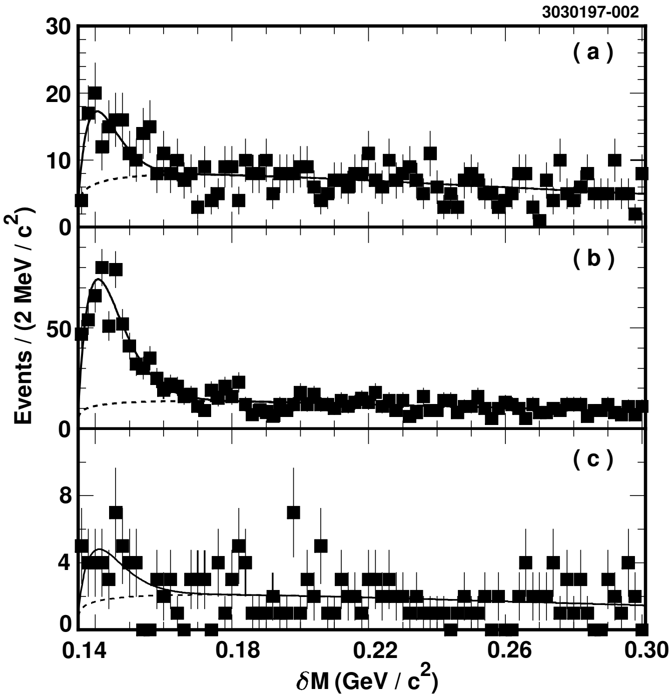

FIG. 2. The δm spectra for data passed through the a) $D^+ \to \pi^0 e^+ \nu_e$ analysis with $0.115 \leq M_{\pi^0_F} < 0.153$ GeV/c^2, b) $D^+ \to \overline{K^0} e^+ \nu_e$ analysis with $0.48 \leq M_{K^0_S} < 0.52$ GeV/c^2, and c) $D^+ \to \eta e^+ \nu_e$ analysis with $0.51 \leq M_\eta < 0.58$ GeV/c^2. The solid line indicates the total fit while the dashed line indicates the background function.

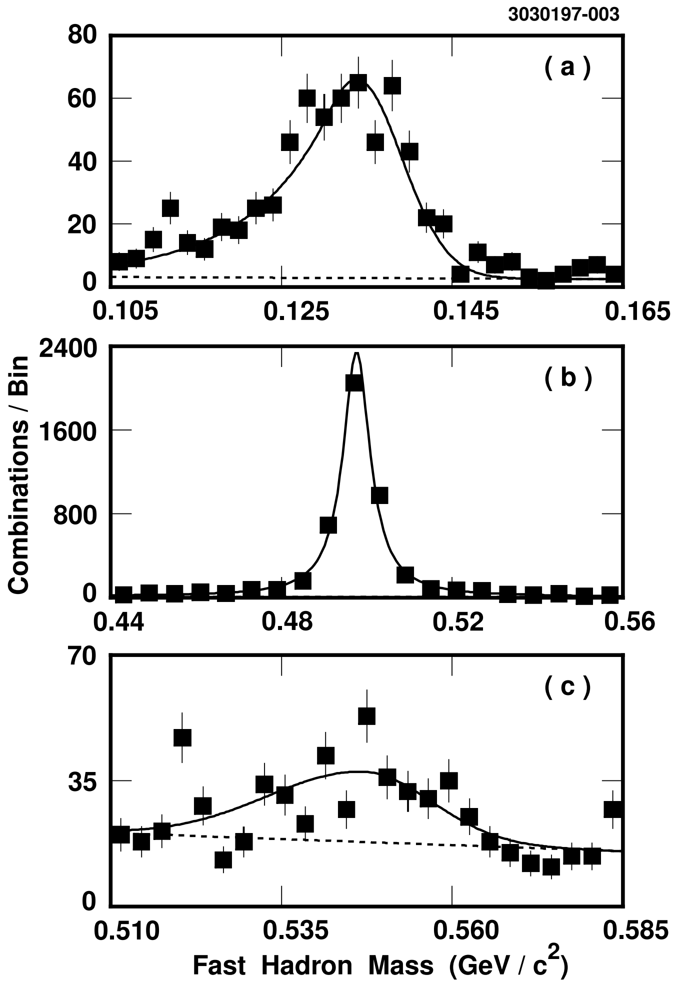

FIG. 3. The a) $M_{\gamma\gamma} = M_{\pi^0_F}$, b) $M_{\pi^+\pi^-}$, and c) $M_{\gamma\gamma} = M_\eta$ spectra for data passed through the $D^+ \to \pi^0 e^+ \nu_e$, $D^+ \to \overline{K^0} e^+ \nu_e$, and $D^+ \to \eta e^+ \nu_e$ analyses, respectively, with $\delta m < 0.3$ GeV/c^2. The solid line indicates the total fit while the dashed line indicates the background function.