RECENT RESULTS FROM CLEO

DORIS YANGSOO KIM
Representing the CLEO-c Collaboration
Loomis Lab of Physics, 1110 W Green St,
Urbana, IL. 61801, USA

We report the initial results from CLEO-c based on the 55.8 pb^{-1} data obtained at the $\psi(3770)$ resonance last year. We give a concise summary of the various CLEO-c analyses on leptonic and semileptonic decays of neutral and charged Dmesons. The data used for this report is the first part of the $\psi(3770)$ data sets to be collected during next several years using the Cornell Electron Storage Ring. Most of the results shown here have already better or the same level of precision compared to the 2004 world averages compiled by the Particle Data Group. [1]

1 CESR-c and CLEO-c

The venerable Cornell Electron Storage Ring (CESR) had been running at the B physics energy region during last decade. Recently, a decision was made to run CESR at lower energies to pursue next generation precision physics in other interesting fields including the charm sector. To accomplish this task, twelve superconducting wigglers have been added to the Storage Ring. The wigglers increase the synchrotron radiation of electron and positron beams, damping the beams. As the result, the luminosity at low beam energies becomes increased. The modified Storage Ring can handle beam energies between 1.5 and 5.6 GeV. The current run plan includes CESR operations at the ψ', $\psi(3770)$ and J/ψ resonances and the $D_s^+ D_s^-$ pair threshold area.

The CLEO-c detector is almost the same as the CLEO III detector. Most of the CLEO III detector components are retained. The old silicon vertex detector of CLEO III was replaced by a new inner drift chamber with six layers. The magnetic field was decreased from 1.5 T to 1.0 T to accommodate lower beam energy accelerator operations.

1.1 Impacts of the CLEO-c Measurements

The leptonic and semileptonic decay kinematics of D mesons is computed from first principles using the Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix elements. The hadronic complications are contained in a few functional forms. In the leptonic decays, the strong interactions are represented by decay constants f_{D^+} and f_{D_S} for D^+ and D_s^+ decays, respectively, which can be calculated by Lattice QCD. In the semileptonic decays, the strong interactions are represented by form factors, which are calculable by various methods. The precision measurement of these parameters will validate and enhance Lattice QCD calculations and test theoretical form factor models, which will improve B meson decay constant and form factor calculations. Subsequently, all these improvements will be used to test unitarity of the CKM matrix.

The large size of samples with fairly clean background conditions expected from CESR-c operations implies excellent opportunities to improve branching fraction measurements of many important decay modes of D mesons. Hadronic decays of D mesons provide information for strong interaction phases essential for CP violation studies. The initial states of D mesons created at CESR-c are coherent, which generate an ideal environment to study mixing and CP violation at the charm sector.

One of the most important goals of the precision flavor physics is to measure all the CKM matrix elements and associated phases, to over-constrain the unitary triangles. CLEO-c will contribute to this effort by reducing uncertainties of V_{cd} and V_{cs} down to the 1.7% level by exploiting D meson decays. Together with the coming results from Lattice QCD, B factories and $p\overline{p}$ collider experiments, the precision of the related CKM matrix elements in the beauty and top sectors will be greatly improved. The uncertainty on V_{cb} is expected to be reduced to the 3% level and the uncertainties on V_{ub}, V_{td} and V_{ts} are expected to be reduced to the 5% level. [2]

1.2 Analysis Techniques at the $\psi(3770)$ Resonance

When the electron and positron beams of CESR collide at the $\psi(3770)$ resonance, the resulting $D\overline{D}$ pairs are created at threshold energy. There are no extra fragmentation particles other than the D mesons at the production vertex, which provides a simple geometry to reconstruct the event. The combinatoric backgrounds coming from wrong assignment of decay tracks are small. Reconstruction of unseen neutrinos in leptonic and semileptonic decays of D mesons becomes quite clean and straightforward. To identify the observed events as $D\overline{D}$ pairs, we first reconstruct a D meson fully as "the tag," then we analyze the decay of the second D in the same event to extract exclusive or inclusive properties. The tagging efficiency of $D\overline{D}$ pair events is high, estimated as $\approx 25\%$ of all the D mesons produced. (Charge conjugate modes are implied in this report.)

1.3 Tagged D Samples from CLEO-c

From December 2003 to March 2004, we collected the first 55.8 pb^{-1} of CLEO-c data at the $\psi(3770)$ resonance with 6 wigglers, generating 360,000 $D\overline{D}$ pairs. All the studies except the last topic on the CP violation shown in this report are based on this data set. After applying basic selection cuts, we used beam energy information and 4-momentum conservation condition to finalize tagged D meson samples. The variables used for this stage of selection and for estimating the number of signals are the difference in the energy ($\Delta E = E(D) - E_{\rm beam}$) and the beam energy constrained mass ($M_{BC} = \sqrt{E_{\rm beam}^2 - |p(D)|^2}$). For example, to measure exclusive semileptonic branching fractions of D^0 (D^+) mesons, we selected $\approx$ 60,000 (32,000) decays using eight (six) hadronic decay modes of $\overline{D}^0$ (D^-) as tags.

2 Leptonic Decays of D Mesons: $D^+ \to \mu^+\nu$

We published a clean observation of the $D^+ \to \mu^+\nu$ decays last year.[6] To select pure $D^+ \to \mu^+\nu$ signals, we required a D^- hadronic tag in the system as the other D meson and an additional charged track as the μ^+ from the signal D meson. We limited the energy of most energetic extra shower to be less than 250 MeV. Since there should be one unseen neutrino in the system, the genuine signal events have to generate a peak at 0 when we plot distributions of "missing mass squared", ($\mathrm{MM}^2 = (E_{\mathrm{beam}} - E_{\mu^+})^2 - (-\vec{p}_{D^-} - \vec{p}_{\mu^+})^2$).

Figure 1 shows the distribution of missing mass squared from our data. From 28651 D^- tagged events, we found eight signal candidates. The size of the backgrounds at the signal area was estimated as one event. The larger peak at 0.25 GeV^2 represents backgrounds coming from $D^+ \to \overline{K}^0\pi^+$ decays. A K_L may escape the detector without depositing energy in the Electromagnetic calorimeter, faking a neutrino signal. We measured branching fraction of our signal mode as $B(D^+ \to \mu^+\nu) = (3.5 \pm 1.4 \pm 0.6) \times 10^{-4}$. From this number, we extracted the decay constant $\mathrm{f_{D^+}}$ using the following equation,

$$B(D^+ \to \mu^+\nu)/\tau_{D^+} = \frac{G_F^2}{8\pi} f_{D^+}^2 m_\mu^2 M_{D^+} \left(1 - \frac{m_\mu^2}{M_{D^+}^2}\right) |V_{cd}|^2 \tag{1}$$

Since the uncertainty of V_{cd} is 1.1 % from the 3 generation unitarity constraint and the uncertainty of τ_{D^+} from experimental measurements is only 0.3 %, we obtained $\mathrm{f_{D^+}} = (202 \pm 41 \pm 17)$ MeV, which is far more accurate than the recent measurement by BES II, $(371^{+129}_{-119} \pm 25)$ MeV, based on three observed events.[3]

3 Exclusive Semileptonic Branching Fractions of D Mesons

To select semileptonic decays of D^0 and D^+ mesons, we first required one fully reconstructed hadronic D tag as the other D meson. From the remaining tracks and showers in the same event, we reconstructed a semileptonic signal candidate. We used a fit variable $U = E_{miss} - |P_{miss}|$ to estimate the number of signal events. Since there should be one unseen neutrino in the system, this variable produces a prominent signal peak at 0. We studied four decay channels of D^0 and five decay channels of D^+. Two of these decay channels were observed for the first time: $D^0 \to \rho^- e^+\nu$ and $D^+ \to \omega e^+\nu$. The U distribution of each channel is shown in Figures 2 and 3 and the results are summarized in Table 1.[4,5] The uncertainties of our measurements are better or at the same level of the 2004 world averages compiled by the Particle Data Group (PDG).[1]

4 Studies on Inclusive Decays of D Mesons

The uncertainties of the current world average of the inclusive semileptonic branching fractions are 0.28 % and 1.9 % for $D^0 \to Xe^+\nu$ and $D^+ \to Xe^+\nu$ decays, respectively. The preliminary study on the first 55.8 pb^{-1} data showed that our statistical uncertainties are expected at the level of 0.2 % and 0.3 % for these decays. We required one hadronic D tag as the other D meson, and one good electron identified by dE/dx, RICH and Electromagnetic calorimeter information. We used the sign relation between the signal and the tag D's to subtract wrong sign events as backgrounds. (For D^0, the signal charge is defined by the charge of its decay particle, K.)

5 CP Violation search in $D^0 \to K_s\pi^+\pi^-$ Decays Based on the CLEO II.V data

According to the Standard Model expectations, CP violation may happen in the $D^0 \to K_S^0\pi^+\pi^-$ decays at the 10^{-6} level due to K^0–$\overline{K}^0$ mixing. Any observation of CP violation larger than this level will indicate new physics. Last year, we published a paper on this subject using a newly developed Dalitz technique. Since this method measures decay amplitudes rather than decay rates, the sensitivity to new physics is greatly enhanced. From the CLEO II.V data, we extracted the CP asymmetry in this decay channel as $A_{CP} = -0.009 \pm 0.021^{+0.010+0.013}_{-0.043-0.037}$. which is interpreted as a non-observation of CP violation.[7] Figure 4 shows the various projections of Dalitz fits on the $D^0 \to K_s\pi^+\pi^-$ decay candidates. The plots in the left column represent the sum of the D^0 and charge conjugate $\overline{D}^0$ decays while the plots in right column represent the differences between the D^0 and $\overline{D}^0$ decays.

6 Summary and Future

Based on the first 55.8 pb^{-1} data collected by CLEO-c at the $\psi(3770)$ resonance, we obtained a clean sample of $D^+ \to \mu^+\nu$ decays and measured their decay constant as $\mathrm{f_{D^+}} = (202 \pm 41 \pm 17)$ MeV. Using the same data set, we produced the results on the exclusive branching fractions of semileptonic decays of D^0 and D^+ mesons. The statistical power of these results are already at the world best level, and two decay modes, $D^0 \to \rho^- e^+\nu$ and $D^+ \to \omega e^+\nu$, were observed for the first time. We are actively studying inclusive branching fractions of D mesons decays, getting promising results. Currently, CESR-c and CLEO-c are collecting more data at the $\psi(3770)$ resonance with 12 wigglers. We have already collected ≈ 280 pb^{-1} at this energy and we are planning to run on the D_s pair threshold area and other interesting beam energies in future.

Acknowledgments

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References

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Table 1: The exclusive branching fraction measurements of D^0 and D^+ meson decays based on the first 55.8 pb^{-1} data from CLEO-c at the $\psi(3770)$ resonance. The branching fractions for $D^0 \to K^{*-}e^+\nu$ and $D^+ \to \overline{K}^{*0}e^+\nu$ are reduced by 2.4% to subtract the non-resonant s-wave contribution.

Decay Mode	B (%) (here)	B (%) (PDG 2004)
$D^0 \to K^- e^+\nu$	$3.44 \pm 0.10 \pm 0.10$	3.58 ± 0.18
$D^0 \to \pi^- e^+\nu$	$0.262 \pm 0.025 \pm 0.008$	0.36 ± 0.06
$D^0 \to K^{*-}(K^-\pi^0)e^+\nu$	$2.11 \pm 0.23 \pm 0.10$	
$D^0 \to K^{*-}(K^0_S\pi^-)e^+\nu$	$2.19 \pm 0.20 \pm 0.11$	
$D^0 \to K^{*-}e^+\nu$	$2.16 \pm 0.15 \pm 0.08$	2.15 ± 0.35
$D^0 \to \rho^- e^+\nu$	$0.194 \pm 0.039 \pm 0.013$	
$D^+ \to \overline{K}^0 e^+\nu$	$8.71 \pm 0.38 \pm 0.37$	6.7 ± 0.9
$D^+ \to \pi^0 e^+\nu$	$0.44 \pm 0.06 \pm 0.03$	0.31 ± 0.15
$D^+ \to \overline{K}^{*0}(K^-\pi^+)e^+\nu$	$5.56 \pm 0.27 \pm 0.23$	5.5 ± 0.7
$D^+ \to \rho^0(\pi^+\pi^-)e^+\nu$	$0.21 \pm 0.04 \pm 0.01$	0.25 ± 0.10
$D^+ \to \omega(\pi^+\pi^-\pi^0)e^+\nu$	$0.16^{+0.07}_{-0.06} \pm 0.01$	

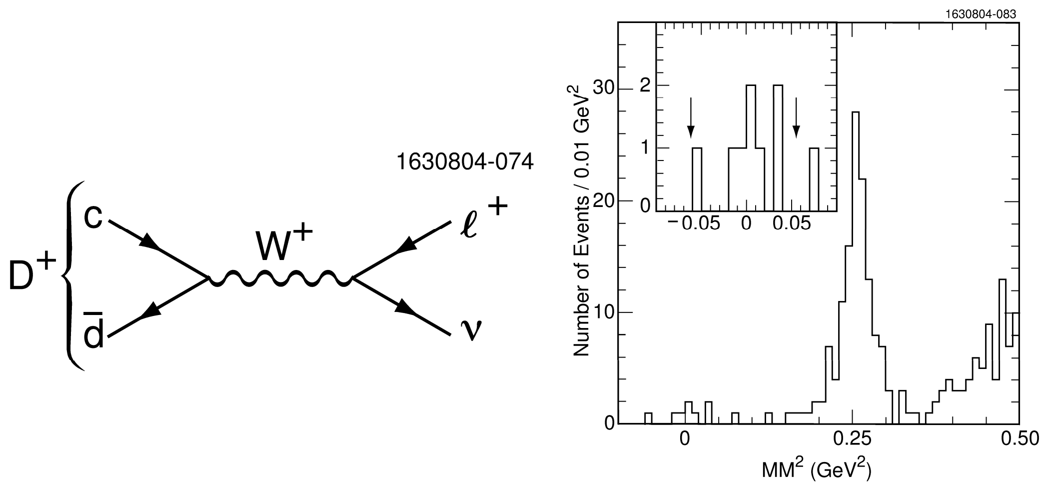

Figure 1: The left plot is the Feynman diagram of the $D^+ \to \mu^+\nu$ decays. The right plot is the distribution of missing mass squared of the $D^+ \to \mu^+\nu$ candidates. The inset plot shows the details in the signal area with the arrows indicating selection cuts. The larger peak at 0.25 GeV^2 represents backgrounds coming from $D^+ \to \overline{K}^0\pi^+$ decays.

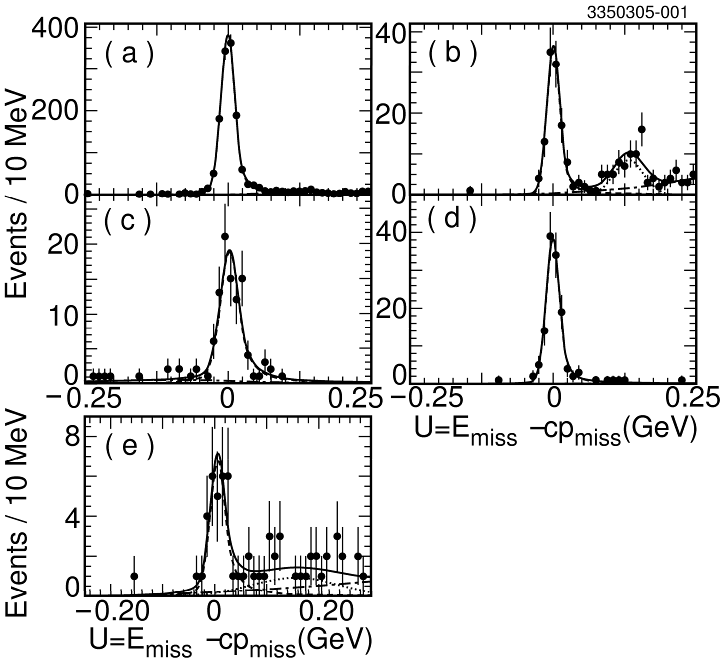

Figure 2: Plots of $U = E_{miss} - |P_{miss}|$ for the study of exclusive branching fractions of D^0 decays. Plots (a), (c) and (d) represent Cabibbo favored while Plots (b) and (e) represent Cabibbo suppressed decay modes. The smaller peaks next to the signal peaks in the Cabibbo suppressed mode plots represent backgrounds coming from the corresponding Cabibbo favored modes. (a) $D^0 \to K^- e^+ \nu$, (b) $D^0 \to \pi^- e^+ \nu$, (c) $D^0 \to K^{*-} e^+ \nu$ ($K^{*-} \to K^- \pi^0$), (d) $D^0 \to K^{*-} e^+ \nu$ ($K^{*-} \to K^0_S \pi^-$), (e) $D^0 \to \rho^- e^+ \nu$ ($\rho^- \to \pi^- \pi^0$). We observed $D^0 \to \rho^- e^+ \nu$ decays for the first time in the world.

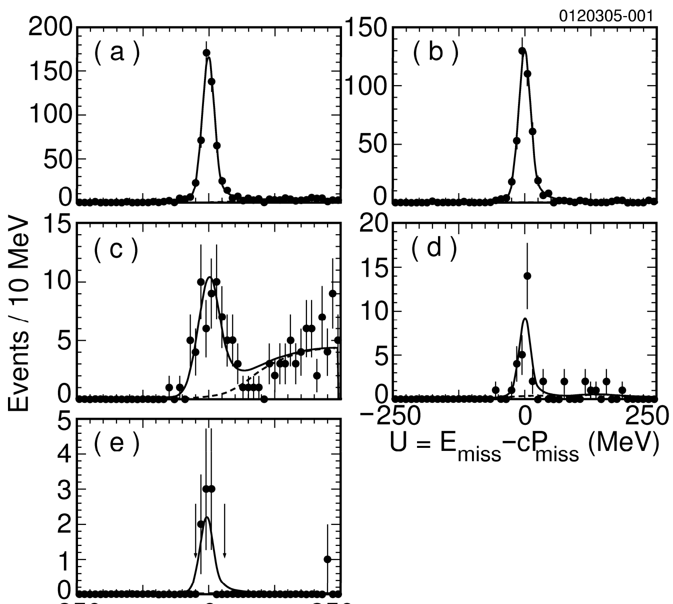

Figure 3: Plots of $U = E_{miss} - |P_{miss}|$ for the study of exclusive branching fractions of D^+ decays. The left column plots of the first two rows represent Cabibbo favored decay modes. All the other plots represent Cabibbo suppressed decay modes. (a) $D^+ \to \overline{K}^0 e^+ \nu$, (b) $D^+ \to \pi^0 e^+ \nu$, (c) $D^+ \to \overline{K}^{*0} e^+ \nu$ ($\overline{K}^{*0} \to K^- \pi^+$), (d) $D^+ \to \rho^0 e^+ \nu$ ($\rho^0 \to \pi^+ \pi^-$), (e) $D^+ \to \omega e^+ \nu$ ($\omega \to \pi^+ \pi^- \pi^0$). We observed $D^+ \to \omega e^+ \nu$ decays for the first time in the world.

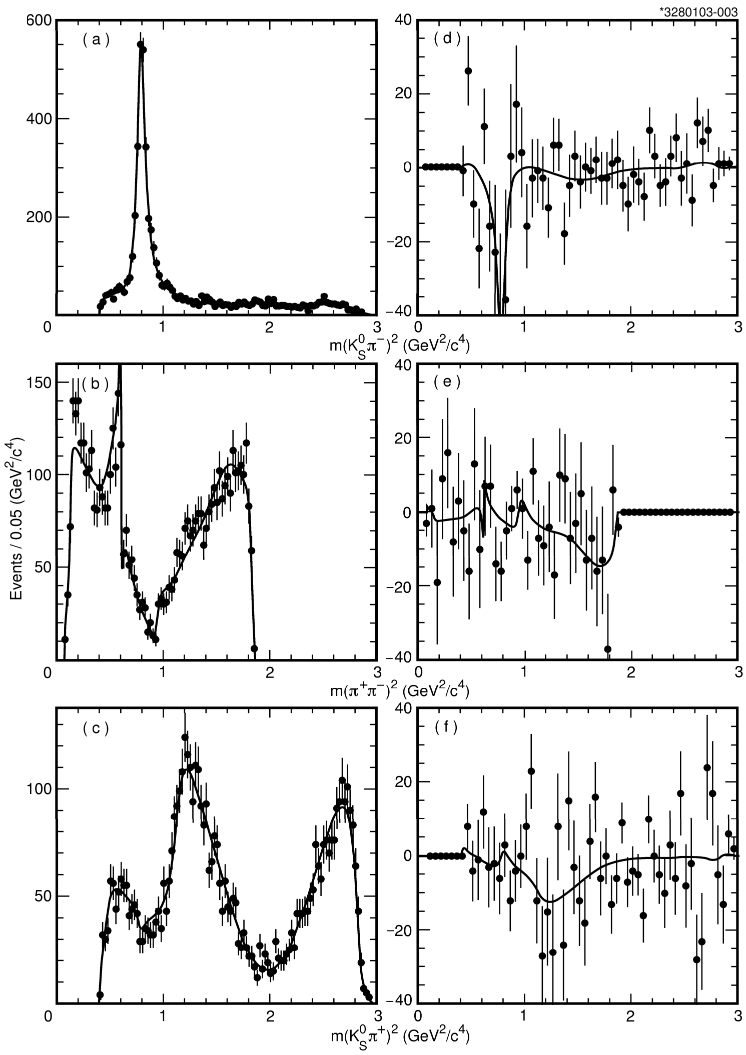

Figure 4: The projections of Dalitz fits on the $D^0 \to K_s\pi^+\pi^-$ decays from the CLEO II.V data. The plots in the left column represent the sum of the D^0 and $\overline{D}^0$ candidates. The plots in right column represent the differences between the D^0 and $\overline{D}^0$ candidates.