CLEO-c Charm Leptonic & Semileptonic Decays

Chul Su Park

University of Rochester
(for the CLEO Collaboration)

March 5, 2008
**Charm Leptonic and Semileptonic Decays**

- Careful studies of charm leptonic and semileptonic decays calibrates theory, so more reliable values of $V_{td}$, $V_{ub}$, can be obtained from $B$ factories.

- **Leptonic decays**

  $\bar{B}^0 \rightarrow W^- W^+ V_{td}$
  \[ \text{Rate} \propto f_B^2 |V_{td}|^2 \]

  $B^0 \rightarrow W^- W^+ V_{td}$
  \[ \text{Rate} \propto f_B^2 |V_{td}|^2 \]

  LQCD predicts $f_B/f_D$ and $f_B/f_{B_s}$ w/ small errors ⇒ precise $f_D$ gives precise $f_B$ and $|V_{td}|$
  $f_D/f_{D_s}$ checks $f_B/f_{B_s}$ and allows precise $|V_{td}|/|V_{ts}|$

- **Semileptonic decays**

  $D^+ \rightarrow f_{D(s)} W^+ V_{cd}(s)$
  \[ \text{Rate} \propto f_{D(s)}^2 |V_{cd}(s)|^2 \]

  $D^0 \rightarrow f(q^2) \pi^-$
  \[ \text{Rate} \propto |V_{cd}|^2 |f_+(q^2)|^2 \]

  Test theory calculations of $f_+(q^2)$ in the $D$ system and apply them to the $B$ system for $|V_{ub}|$
Cleo-c Open Charm Program

- Precision measurements of benchmark branching fractions of $D^0$, $D^+$, and $D_s^+$, i.e., those decay modes used by $B$ factories and hadron colliders: $D^0 \rightarrow K^-\pi^+$, $D^+ \rightarrow K^-\pi^+\pi^+$, $D_s^+ \rightarrow \pi^+K^+K^-$, and others.

- Measurements to test, calibrate, validate Lattice QCD calculations, other calculations of strong interaction effects. $D^+$, $D_s^+ \rightarrow l^+\nu_l$, $D$ exclusive semileptonic decays.

- General-purpose symmetric detector
- Particle ID ($dE/dx$, Ring Imaging Cherenkov) excellent in our momentum region
- Tracking: $\delta p/p = 0.6\%$ at 1 GeV
- CsI calorimeter: $\delta E/E \sim 5\%$ at 100 MeV
Data Samples

$D D \bar{D}$  $D_{s}^{*} \bar{D}_{s}$

* $D D \bar{D}$ @ 3770 : 800 pb$^{-1}$ (56 & 281 pb$^{-1}$ in this talk);
  281 pb$^{-1}$ $\sim$ 1.8 $\times$ 10$^{6}$ $D D \bar{D}$

* $D_{s}^{*} \bar{D}_{s}$ @ 4170 : 314 pb$^{-1}$ (will double the sample);
  314 pb$^{-1}$ $\sim$ 0.3 $\times$ 10$^{6}$ $D_{s}^{*} \bar{D}_{s}$
Charm at $\psi(3770)$

- $\psi(3770) \rightarrow D\bar{D}$: just above threshold, no additional particles
  \[ \Delta E = E_D - E_{\text{beam}} \]
  \[ M_{bc} = \sqrt{E_{\text{beam}}^2 - |\vec{p}_D|^2} \]

- $D$ tagging efficiency: ~10% $D^+$
  ~15% $D^0$

- Clean experimental environment (← low multiplicity & $D$-tagging)

- Absolute branching fraction measurement (← $D$ tagging)
- CLEO-c has largest data set at 3770
Absolute Branching Fractions

Semileptonic event can be fully reconstructed (except neutrino)

\[ \mathcal{B}(D \rightarrow X e^+ \nu_e) = \frac{N_{SL}/\epsilon_{SL}}{N_{tag}} \]

\[ U = E_{\text{miss}} - |\vec{p}_{\text{miss}}| \text{ (GeV)} \]
Introduction : Leptonic Decays

\[ \Gamma(P_Qq \rightarrow \ell^+ \nu_\ell) = \frac{G_F^2 |V_{Qq}|^2 f_P^2}{8\pi} m_Qq m_\ell^2 \left(1 - \frac{m_\ell^2}{m_{Qq}^2}\right)^2 \]

- Measure rates to extract decay constant \( f_P \) (\( V_{Qq} \)).
- Check lattice calculations of decay constants.
  - \( f_D \) at CLEO-c and \((f_B/f_D)_{\text{LQCD}} \Rightarrow f_B\) for precise \( |V_{td}| \).
  - \( f_D/f_{D_s} \) checks \((f_B/f_{B_s})_{\text{LQCD}}\) for \( |V_{td}|/|V_{ts}| \).
- Sensitive to new physics, e.g. \( H^+ \) can mediate.
$D^+ \rightarrow \mu^+ \nu_\mu$

- Use $158k D^-$ tags (281 pb$^{-1}$ @3770)
- Require only one additional track, $\mu^+$
- Reject event if substantial energy in calorimeter
- Compute missing mass


- $B(D^+ \rightarrow \mu^+ \nu_\mu) = (4.40 \pm 0.66^{+0.09}_{-0.12}) \times 10^{-4}$
- $f_D = (222.6 \pm 16.7^{+2.8}_{-3.4})$ MeV (using $|V_{cd}| = 0.2238$)

- Unquenched LQCD $f_{D^+} = (201 \pm 3 \pm 17)$ MeV, Exp/Theory agree $\sim$ to 10%.
\begin{align*}
D_s^+ & \rightarrow \mu^+ \nu_\mu \\
D_s^+ & \rightarrow \tau^+ \nu_\tau \ (\tau^+ \rightarrow \pi^+ \bar{\nu}_\tau)
\end{align*}

- 314 pb\(^{-1}\) @ 4170 – \(e^+e^- \rightarrow D_s^0 D_s^{*0}\)
- Find a \(D_s\) (8 tag modes used), 31k tag candidates
- Now include a \(\gamma\), looking for \(D_s^{*0} \rightarrow \gamma D_s\) decay \(\gamma\)
- Calculate mass recoiling against \(D_s\)-tag + \(\gamma\), to find events with detected decay \(\gamma\)
- Select events with only one additional track, oppositely charged, consistent with \(\mu\) or \(\pi\)
- Reject events with energetic neutral energy clusters
- Calculate missing mass.


- A: 
  \[ B(D_s^+ \rightarrow \mu^+ \nu_\mu) = (0.594 \pm 0.066 \pm 0.031)\%
\]
- B and C: 
  \[ B(D_s^+ \rightarrow \tau^+ \nu_\tau) = (8.0 \pm 1.3 \pm 0.4)\%
\]
- A, B, and C: by summing all cases, w/ SM \(\tau/\mu\) ratio
  \[ B^{\text{eff}}(D_s^+ \rightarrow \mu^+ \nu_\mu) = (0.638 \pm 0.059 \pm 0.033)\%
\]

\[ f_{D_s} = (274 \pm 13 \pm 7) \text{ MeV} \ (|V_{cs}| = 0.9738) \]

<table>
<thead>
<tr>
<th>Case</th>
<th>Region (GeV(^2))</th>
<th>Signal</th>
<th>Background</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-0.05 &lt; MM(^2) &lt; 0.05</td>
<td>92</td>
<td>3.5±1.4</td>
</tr>
<tr>
<td>B</td>
<td>0.05 &lt; MM(^2) &lt; 0.20</td>
<td>31</td>
<td>2.5±1.1</td>
</tr>
<tr>
<td>C</td>
<td>-0.05 &lt; MM(^2) &lt; 0.20</td>
<td>25</td>
<td>3.0±1.3</td>
</tr>
<tr>
<td>Sum</td>
<td>-0.05 &lt; MM(^2) &lt; 0.20</td>
<td>148</td>
<td>9.0±2.3</td>
</tr>
</tbody>
</table>
$D_s^+ \rightarrow \tau^+ \nu_\tau \ (\tau^+ \rightarrow e^+ \nu_e \bar{\nu}_\tau)$

- 298 pb$^{-1}$ @ 4170 – $e^+ e^- \rightarrow D_s D_s^*$
- Find a $D_s$ (3 cleanest tag modes used), 13k tag candidates
- Find an electron on the other side
- Require no other charged tracks on the other side
- Plot the energy in the calorimeter, not due to tag side or the electron
- $E_{\text{extra}} < 400$ MeV is the signal region
- Extrapolate background from $D_s$ semileptonic decays (mainly $D_s^+ \rightarrow \eta e^+ \nu_e$) from region above 400 MeV
- $D_s^+ \rightarrow K_S^0 e^+ \nu_e$ background from $D_s^+ \rightarrow K_S^0 e^+ \nu_e$ measurement, $B(D_s^+ \rightarrow K_S^0 e^+ \nu_e) = (0.14 \pm 0.06 \pm 0.01)\%$
- Background is $\sim 21\%$ of yield in signal region
- Result: arXiv:0712.1175

$B(D_s^+ \rightarrow \tau^+ \nu_\tau) = (6.17 \pm 0.71 \pm 0.34)\%$

- This is the most precise determination of $B(D_s^+ \rightarrow \tau^+ \nu_\tau)$
- $f_{D_s} = (273 \pm 16 \pm 8)$ MeV ($|V_{cs}| = 0.9738$)

$N_{DT} = 123 \pm 11.3$

$N_S = 101.6 \pm 11.5$

$N_B = 21.4 \pm 1.0$
$f_{D_s}$ & $f_{D_s}/f_D$

- Combining $D_s^+ \rightarrow \mu^+ \nu_\mu$, $D_s^+ \rightarrow \tau^+(\pi^+ \bar{\nu}_\tau)\nu_\tau$, and $D_s^+ \rightarrow \tau^+(e^+ \nu_e \bar{\nu}_\tau)\nu_\tau$: Phys. Rev. Lett. 99, 071802 (2007); arXiv:0712.1175

\[
f_{D_s} = (274 \pm 10 \pm 5) \text{ MeV}
\]

- Using $f_D = (222.6 \pm 16.7^{+2.8}_{-3.4})$ MeV

\[
\frac{f_{D_s}}{f_D} = 1.23 \pm 0.10 \pm 0.03
\]

- CLEO-c is the most precise result to date for both $f_D$ and $f_{D_s}$ ([294 ± 27] MeV, PDG 2006).

- $R = \frac{\Gamma(D_s^+ \rightarrow \tau^+ \nu_\tau)}{\Gamma(D_s^+ \rightarrow \mu^+ \nu_\mu)} = 11.0 \pm 1.4 \pm 0.6$
  (consistent with lepton universality, SM 9.72).
Comparison with Theory

- CLEO $f_D$ is consistent with LQCD calculations.
- CLEO $f_{D_s}$ is $\sim 3\sigma$ above the most recent & precise LQCD calculation (HPQCD)
  - this discrepancy needs to be studied, LQCD or Exp error?
  - conflicts with the suppression expected from a 2HDM (Phys. Rev. D 75, 075004 (2007))
  - there is new physics that interferes constructively with the SM?

- Comparing measured $f_{D_s}/f_D$
  - Comparing measured $f_{D_s}/f_D$ with HPQCD
    $M_{H^+}/\tan\beta > 2.2$ GeV at 90% C.L.
  - Using HPQCD $f_{D_s}/f_D$
    $|V_{cd}|/|V_{cs}| = 0.217 \pm 0.19_{\text{exp}} \pm 0.002_{\text{theory}}$
Introduction : Semileptonic Decays

- Cleanest (and simplest, both experimentally & theoretically) way to determine magnitudes of CKM elements

\[ |V_{cs}|^2 \propto |V_{cs}(d)|^2 |f_+^{D \rightarrow K(\pi)}(q^2)|^2 \]

- Assuming theoretical form factor
  ⇒ determine $|V_{cs}|$ and $|V_{cd}|$

- Assuming $|V_{cs}|$ and $|V_{cd}|$
  ⇒ we can check theoretical calculations of the form factors

- Test theory calculations (e.g. LQCD) of $f_+(q^2)$ in the $D$ system and apply them to the $B$ system, e.g. for $|V_{ub}|$. 

\[ D \rightarrow K(\pi) + l\nu \quad \Rightarrow \text{HQS} \quad \Rightarrow \quad B \rightarrow \pi l\nu \]
Inclusive \textit{D} Semileptonic Decays

- Historically: interesting due to the large difference in $D^0$ vs $D^+$ lifetimes (spectator model inadequate)
- Inclusive vs Sum of Exclusive: room for new modes?

<table>
<thead>
<tr>
<th>Mode</th>
<th>Branching Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^0 \rightarrow Xe^+\nu_e$</td>
<td>$(6.46 \pm 0.17 \pm 0.13)$%</td>
</tr>
<tr>
<td>Sum of $\mathcal{B}_{SL}(D^0)$</td>
<td>$(6.1 \pm 0.2 \pm 0.2)$%</td>
</tr>
<tr>
<td>$D^+ \rightarrow Xe^+\nu_e$</td>
<td>$(16.13 \pm 0.20 \pm 0.33)$%</td>
</tr>
<tr>
<td>Sum of $\mathcal{B}_{SL}(D^+)$</td>
<td>$(15.1 \pm 0.5 \pm 0.5)$%</td>
</tr>
</tbody>
</table>

- Consistent with isospin symmetry: the lepton cannot interact strongly with the final-state hadrons and the two mesons differ only in the isospin of the light quark

\[ \frac{\Gamma_{D^+}^{SL}}{\Gamma_{D^0}^{SL}} = \frac{\mathcal{B}_{D^+}^{SL}}{\mathcal{B}_{D^0}^{SL} / \tau_0} = 0.985 \pm 0.028 \pm 0.015 \]

\[ \sim 8\% \text{ extrapolation below momentum cutoff} \]
First Observations

\[ D^+ \rightarrow \eta(\gamma\gamma)e^+\nu_e \]  
[ Preliminary]  
32.7 ± 6.7

\[ D^0 \rightarrow \rho^-e^+\nu_e \]  
[ Preliminary]  
131 ± 13

\[ D^+ \rightarrow \eta(\pi^+\pi^-\pi^0)e^+\nu_e \]  
[ Preliminary]  
13.3 ± 4.0

\[ D^+ \rightarrow \omega e^+\nu_e \]  
[ Preliminary]  
37.3 ± 6.7

\[ D^0 \rightarrow K^-\pi^+\pi^-e^+\nu_e \]  

10 signal candidates on
\[ \sim 2 \] background

8 signal consistent with
\[ K^-_{1270} \rightarrow K^-\pi^+\pi^- \]
on \[ \sim 1 \] background

\[ U = E_{\text{miss}} - |\vec{p}_{\text{miss}}| \ (GeV) \]  
\[ U = E_{\text{miss}} - |\vec{p}_{\text{miss}}| \ (GeV) \]  
\[ M_{K\pi\pi} \ (GeV/c^2) \]
**D → K(π)eν**

(1) Tagged Analysis:

[Preliminary]

(2) Untagged Analysis:

The untagged analysis has larger signal yields but larger backgrounds and systematic uncertainties.
Branching Fraction Summary

<table>
<thead>
<tr>
<th>Reaction</th>
<th>PDG 2004</th>
<th>CLEO-c (281 pb(^{-1}))</th>
<th>BES</th>
</tr>
</thead>
<tbody>
<tr>
<td>(D^0 \rightarrow \pi^- e^+ \nu)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D^0 \rightarrow K^- e^+ \nu)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D^0 \rightarrow K^-(K^- \pi^0) e^+ \nu)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D^0 \rightarrow K^- (K^- \pi^-) e^+ \nu)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D^0 \rightarrow \rho^- e^+ \nu)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D^0 \rightarrow K(1270)^- e^+ \nu)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D^0 \rightarrow X e^+ \nu)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D^+ \rightarrow \pi^0 e^+ \nu)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D^+ \rightarrow K^0 e^+ \nu)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D^+ \rightarrow K^0 (K^- \pi^+) e^+ \nu)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D^+ \rightarrow \rho^0 e^+ \nu)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D^+ \rightarrow \omega e^+ \nu)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D^+ \rightarrow \eta e^+ \nu)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D^+ \rightarrow X e^+ \nu)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* \(D \rightarrow K^- e^+ \nu\) branching fractions are for 56/pb

<table>
<thead>
<tr>
<th>(L (\text{pb}^{-1}))</th>
<th>(B(D^0)_{SL} (%))</th>
<th>(B(D^+)_{SL} (%))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(K^- e^+ \nu_e)</td>
<td>3.58 ± 0.05 ± 0.05</td>
<td>8.86 ± 0.17 ± 0.20</td>
</tr>
<tr>
<td>(K^0 e^+ \nu_e)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\pi^- e^+ \nu_e)</td>
<td>0.309 ± 0.012 ± 0.006</td>
<td>0.397 ± 0.027 ± 0.029</td>
</tr>
<tr>
<td>(\pi^0 e^+ \nu_e)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\rho^- e^+ \nu_e)</td>
<td>0.156 ± 0.016 ± 0.009</td>
<td>0.232 ± 0.020 ± 0.012</td>
</tr>
<tr>
<td>(\rho^0 e^+ \nu_e)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\omega e^+ \nu_e)</td>
<td>0.149 ± 0.027 ± 0.005</td>
<td></td>
</tr>
<tr>
<td>(\eta e^+ \nu_e)</td>
<td></td>
<td>0.133 ± 0.020 ± 0.006</td>
</tr>
<tr>
<td>(K_1(1270) e^+ \nu_e)</td>
<td>0.076 ± 0.041 ± 0.006 ± 0.007</td>
<td></td>
</tr>
</tbody>
</table>

\[\sum_{\text{exclusive}}\] 6.28 ± 0.16\(_{\text{stat}}\) 15.33 ± 0.42\(_{\text{stat}}\)

\[\sum_{\text{exclusive}}\] \(X e^+ \nu_e\) \(6.46 ± 0.17 ± 0.13\) \(X e^+ \nu_e\) \(16.13 ± 0.20 ± 0.33\)

\[\sum_{\text{exclusive}}\] \(\eta' e^+ \nu_e < 3.5 \times 10^{-4}\) \(\phi^- e^+ \nu_e < 1.6 \times 10^{-4}\)

- 281 pb\(^{-1}\) numbers are preliminary, except \(Xe\nu\), \(K_1(1270)e\nu\), and \(K/\pi e\nu\) (\(\nu\)-recon).
- 40% overlap, do not average tagged/\(\nu\)-recon \(K/\pi e\nu\).
Semileptonic Decay Form Factor

\[ q^2 = (p_D - p_X)^2 = m_D^2 + m_X^2 - 2m_DE_X^* \]

Amplitude factorizes
\[ \mathcal{M}(D \rightarrow X\ell^+\nu_\ell) = -i \frac{G_F}{\sqrt{2}} V_{cs(d)}^* L_\mu H_\mu \]

- Hadronic currents: in the limit \( m_\ell \rightarrow 0 \)
  - \( P \rightarrow P'\ell^+\nu_\ell \): single form factor, \( H_\mu = f_+(q^2)(P_P + P_{P'})^\mu \)
    (gold-plated for both theory and experiment)
  - e.g. \( D \) semileptonic decays to a pseudoscalar can be written as
    \[ \frac{d\Gamma(D \rightarrow Ke\nu_e)}{dq^2} = \frac{G_F^2 |V_{cs}|^2 p_K^3}{24\pi^3} |f_+(q^2)|^2. \]

- The messy hadronic physics is contained in the form factor.
  The full test of LQCD is its ability to calculate \( f(q^2) \), both the shape vs \( q^2 \), and the absolute value.
Form Factor: parametrizations

- In general: 
  \[ f_+(q^2) = \frac{f_+(0)}{1-\alpha} \frac{1}{1-q^2/m_{\text{pole}}^2} + \sum_{k=1}^{N} \frac{\rho_k}{1-\frac{1}{\gamma_k q^2/m_{\text{pole}}^2}} \]

- Single pole: 
  \[ f_+(q^2) = \frac{f_+(0)}{1-q^2/m_{\text{pole}}^2} \]

- Modified pole: 
  \[ f_+(q^2) = \frac{f_+(0)}{(1-q^2/m_{\text{pole}}^2)(1-\alpha q^2/m_{\text{pole}}^2)} \]
  (allows for additional poles).

  \[ f_+(q^2) = \frac{1}{P(q^2)\phi(q^2, t_0)} \sum_{k=0}^{\infty} a_k(t_0)[z(q^2, t_0)]^k, \]
  with 
  \[ z(q^2, t_0) = \frac{\sqrt{t_+ - q^2} - \sqrt{t_+ - t_0}}{\sqrt{t_+ - q^2} + \sqrt{t_+ - t_0}}, \]
  \[ t_\pm \equiv (M_D \pm m_P)^2, \]
  \[ P(q^2) \equiv 1 \ (D \to \pi) \text{ or } z(q^2, M_{D^*_s}^2) \ (D \to K). \]

  With current CLEO-c data we only resolve the first 2–3 terms in the series expansion.

- Experiment probes both the form factor magnitude & parametrization.
**$D \to K e^+ \nu_e$: high statistics test of shape & absolute normalization of $f_+(q^2)$**

- **Modified pole model used for comparison:**
  \[ f_+(q^2) = \frac{f_+(0)}{(1-q^2/m^2_{\text{pole}})(1-\alpha q^2/m^2_{\text{pole}})} \]

- **Shape parameter:** CLEO-c prefers smaller value

- **Normalization:**
  experiment (2%) consistent with LQCD (10%)

- CLEO-c (tag) – Preliminary
- CLEO-c (no tag) – arXiv:0712.0998

---

**Assuming $V_{cs} = 0.9745$**

![Graph showing data points and model predictions for $D \to K e^+ \nu_e$ decay.](image)
\(D \to \pi e\nu\): high statistics test of shape & absolute normalization of \(f_+(q^2)\)

- Modified pole model used for comparison:
  \[
f_+(q^2) = \frac{f_+(0)}{(1-q^2/m_{\text{pole}}^2)(1-\alpha q^2/m_{\text{pole}}^2)}
\]
- Shape parameter: experiments compatible with LQCD
- Normalization: experiment (4\%) consistent with LQCD (10\%)
  - CLEO-c (tag) – Preliminary
  - CLEO-c (no tag) – arXiv:0712.0998
We use the model independent Becher-Hill series parametrization for $V_{cx}$ (determine $f_+(0)|V_{cx}|$ then use theory value of $f_+(0)$).
**$|V_{cs}|$ & $|V_{cd}|$ Results**

Combined measured $|V_{cx}|f_+(0)$ values using Becher-Hill parameterization with FNAL/MILC/HPQCD for $f_+(0)$.

- **CLEO-c**: the most precise direct determination of $|V_{cs}|$
- $\sigma(|V_{cs}|)/|V_{cs}| \sim 1.5\%$ (exp) $\oplus$ 10\% (theory)

| CLEO-c          | $|V_{cs}|$          |
|-----------------|---------------------|
| (tagged)        | $1.014 \pm 0.013 \pm 0.009 \pm 0.106$ |
| (untagged)      | $1.015 \pm 0.010 \pm 0.011 \pm 0.106$ |

- **CLEO-c**: $\sigma(|V_{cd}|)/|V_{cd}| \sim 4.5\%$ (exp) $\oplus$ 10\% (theory)
- $\nu N$ remains most precise determination (for now).

| CLEO-c          | $|V_{cd}|$          |
|-----------------|---------------------|
| (tagged)        | $0.234 \pm 0.010 \pm 0.004 \pm 0.024$ |
| (untagged)      | $0.217 \pm 0.009 \pm 0.004 \pm 0.023$ |

- Tagged and untagged are consistent.
- 40% overlap, DO NOT AVERAGE.
- **CLEO-c** (tag) – Preliminary
- **CLEO-c** (no tag) – arXiv:0712.0998
Summary

■ $D$ Leptonic:
  ◆ $f_D$ measured to $\pm 7.6\%$, statistical error dominates.
  ◆ $f_{D_s}$ measured to $\pm 4.1\%$, statistical error dominates.
  ◆ $B(D_s^+ \rightarrow \tau^+\nu_\tau)/B(D_s^+ \rightarrow \mu^+\nu_\mu)$ consistent with theory.
  ◆ For $f_{D_s}$, a suggestion of a disagreement with LQCD $\sim 3\sigma$.

■ $D$ Semileptonic:
  ◆ Inclusive $D^0$, $D^+$ semileptonic widths $\sim$ equal.
  ◆ Sum of measured exclusives almost saturates inclusives.
  ◆ $D \rightarrow Ke\nu$, $\pi e\nu$ form factors in general agreement with LQCD.

■ With CLEO-c full data: $800 \text{ pb}^{-1}$ @3770 & $600 \text{ pb}^{-1}$ @4170
  ◆ Expect errors in $f_D$ & $f_{D_s}$ decreased to a few % level.
  ◆ More stringent tests of theory for $D \rightarrow K(\pi)e^+\nu_e$ form factor $f_+(0)$ & shape.