Charm Meson
Decay Constants

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Leptonic decays provide a clean way to probe strong interactions. Measure rates to extract decay constant $f_D$. Calibrate lattice calculations of decay constants, so more reliable values of $|V_{td}|$ and $|V_{ts}|$ can be obtained from $B$ factories:

- $f_D$ 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 $|V_{td}|/|V_{ts}|$. 

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

Leptonic decays provide a clean way to probe strong interactions. Measure rates to extract decay constant $f_P$. Calibrate lattice calculations of decay constants, so more reliable values of $|V_{td}|$ and $|V_{ts}|$ can be obtained from $B$ factories:
**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: $D^0 \rightarrow K^-\pi^+$, $D^+ \rightarrow K^-\pi^+\pi^+$, $D_s^+ \rightarrow K^+K^-\pi^+$, and others.
- Measurements to test, calibrate, validate Lattice QCD calculations, other calculations of strong interaction effects: $D^+$, $D_s^+ \rightarrow \ell^+\nu_\ell$, $D$ exclusive semileptonic decays.

- General-purpose symmetric detector
- Particle ID
  
  $(dE/dx, \text{Ring Imaging Cherenkov})$
  excellent in our momentum region
- Tracking: $\delta p/p = 0.6\%$ at 1 GeV
- CsI calorimeter:
  $\delta E/E \sim 5\%$ at 100 MeV
■ CLEO-c: collected large data sets at charm threshold
  - $E_{\text{CM}}$ near 3770MeV: 818 pb$^{-1}$, 3.0M $D^0\bar{D}^0$ and 2.4M $D^+D^-$ events.
  - $E_{\text{CM}}$ near 4170MeV: 600 pb$^{-1}$, 0.6M $D_s^*\pm D_s^\mp$ events.
Experimental Technique

- \( D\bar{D} \) threshold, no additional particles produced.
- Low multiplicity (4 \(~\) 6 tracks per event). Clean experimental environment.
- Event can be fully reconstructed, tagging \( D \) and recoiling signal, missing neutrino can be determined w/o kinematic ambiguity.
- \( \rho_{\text{miss}} = \rho_{\text{CM}} - (\rho_{\text{tag}} + \rho_{\ell}) \)
- Absolute branching fraction from \( N_{\text{signal}}/N_{\text{tag}} \).

![Diagram of particle decay processes]

- \( D^+ \rightarrow \mu^+ \nu_\mu \)
- \( D^+ \rightarrow \bar{K}^0 \pi^+ \)
- CLEO-c 818 pb\(^{-1} \)
\( D\) Tagging – 3770 MeV

- \( e^+ e^- \rightarrow \psi(3770) \rightarrow D\bar{D}\) produced at threshold, no extra particles.
- \( m_{BC} = \left[ E_{\text{beam}}^2 - p_D^2 \right]^{1/2} \)
- 10\% of \( D^-\) tagging, (15\% of \( \bar{D}^0\) tagging) in clean hadronic modes.
- 818 pb\(^{-1}\), \( 4.6 \times 10^5 \) \( D^-\) tags in 6 modes.
\[ D^+ \rightarrow \mu^+ \nu_\mu \]

- Cabibbo- and helicity- suppressed.
- Combine \( D^- \) tag with \( \mu^+ \) candidate, \( E_{\text{cal}} < 300 \) MeV, minimum ionizing.
- Reject events with extra tracks or large extra calorimeter energy.
- \( MM^2 = (p_{\text{CM}} - p_D - p_\mu)^2 \)

- PRD 78, 052003 (2008):
  - \( B = (3.82 \pm 0.32 \pm 0.09) \times 10^{-4} \)
  - \( f_D = (205.8 \pm 8.5 \pm 2.5) \) MeV

- Good agreement with LQCD, PRL 100, 062002 (2008):
  - \( f_D = (207 \pm 4) \) MeV
$D_s$ Tagging – 4170 MeV

- $e^+e^- \rightarrow D_s^*+D_s^-$ produces extra $\gamma$ (94.2%) or $\pi^0$ from $D_s^*$ decay.
- 6% of $D_s^-$ tagging.
- 600pb$^{-1}$, 70.5k tags in 9 modes.

![Graphs showing invariant mass distributions for various decay modes]
\[ D_S^+ \rightarrow \mu^+ \nu_\mu \; \& \; D_S^+ \rightarrow \tau^+ \nu_\tau \; (\tau^+ \rightarrow \pi^+ \bar{\nu}_\tau) \]

- Cabibbo-favored, less helicity-suppressed (\(\tau\)).
- Combine \(D_S^-\) tag, transition \(\gamma\) (\(D_S^* \rightarrow D_s \gamma\)), and additional track.
- Reject events with extra tracks or large extra calorimeter energy.
- \(MM^2 = (p_{CM} - p_{D_s} - p_\gamma - p_{track})^2\)
- Two cases:
  (i) \(E_{cal} < 300\) MeV, minimum ionizing
  (ii) \(E_{cal} \geq 300\) MeV, interacting pion

- PRD 79, 052001 (2009):
  - \(B(\mu\nu) = (5.65 \pm 0.45 \pm 0.17) \times 10^{-3}\)
  - \(B(\tau\nu) = (6.42 \pm 0.81 \pm 0.18)\%\)
\[ D_s^+ \rightarrow \tau^+ \nu_{\tau} \ (\tau^+ \rightarrow e^+ \nu_e \bar{\nu}_{\tau}) \]

- Cabibbo-favored, less helicity-suppressed.
- Three cleanest tag modes are used \((D_s^- \rightarrow \phi\pi^-, K^-K^{*0}, \text{ and } K^0_S K^-)\), 22k tagged events.
- Combine \(D_s^-\) tag with \(e^+\) candidate.
- Reject events with extra tracks.
- Three neutrinos in the final state, use extra calorimeter energy.
- \(E_{\text{extra}} < 400\) MeV.
- \(D^+_s \rightarrow K^0_L e^+ \nu_e\) background from measured \(B(D_s^+ \rightarrow K^0_S e^+ \nu_e)\), dominant systematic uncertainty.

- PRD 79, 052002 (2009):
  - \(B(D_s \rightarrow \tau\nu) = (5.30 \pm 0.47 \pm 0.22)\%\)
CLEO-c and LQCD

- \( f_D \): in good agreement
  - CLEO-c = (205.8 ± 8.5 ± 2.5) MeV
  - LQCD = (207 ± 4) MeV

- \( f_{D_s} \): 2.3σ apart
  - CLEO-c = (259.5 ± 6.6 ± 3.1) MeV
  - LQCD = (241 ± 3) MeV

- \( f_{D_s}/f_D \):
  - CLEO-c = 1.26 ± 0.06 ± 0.02
  - LQCD = 1.164 ± 0.011

- \( R = \frac{\Gamma(D_s \rightarrow \tau \nu)}{\Gamma(D_s \rightarrow \mu \nu)} = 10.1 ± 0.9 ± 0.3 \)
  consistent with lepton universality (SM = 9.76).

\[ [1] \text{CLEO-c: PRD 78, 052003 (2008), PRD 79, 052001 (2009), and PRD 79, 052002 (2009).} \]
\[ [2] \text{LQCD (HPQCD & UKQCD): PRL 100, 062002 (2008).} \]
Summary

- CLEO-c at charm threshold: leptonic decays of charm mesons is an excellent device to test, calibrate, and validate LQCD calculations of strong interaction effects.
- Theory and experiment are both making great strides in precision:
  - CLEO-c $\delta f_D/f_D \sim 4\%$ and $\delta f_{Ds}/f_{Ds} \sim 3\%$.
  - LQCD $\delta f_D/f_D \sim 2\%$ and $\delta f_{Ds}/f_{Ds} \sim 1\%$.
  - Allows for stringent test for LQCD.
- Prospects for charm meson decay constants at BES III: [arXiv:0809.1869], an order bigger sample on open charm
  - Independent cross check at charm threshold.
  - $\sim 1\%$ precision on $f_D$ and $f_{Ds}$.