CLEO-c: Recent Results

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Outline

- Program Overview
  - CLEOIII Result
- CLEO-c
  - Leptonic
  - Semileptonic
  - Hadronic
Impact of Physics

δVud/Vud 0.1%
δVus/Vus = 1%
δVub/Vub 15%

δVcd/Vcd 7%
δVcs/Vcs = 16%
δVcb/Vcb 5%

δVtd/Vtd = 36%
δVts/Vts 39%
δVtb/Vtb 29%

CLEO-c
CLEO-c + Lattice QCD + B factories
CLEO-c + Lattice QCD + B factories + ppbar

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Weak Annihilation $B \rightarrow l\nu(X)$

*Annihilation of valence quarks (leptonic).
*Hadronization of residual “brown muck”.
*Estimates of rate suggest small contribution from these processes. (Order $\sim 1/m_H^3$)
*However rate can be concentrated at high $q^2$.

\[
\Gamma_{WA}/\Gamma_{btou} \approx 0.03 \left( \frac{f_B}{0.2 \text{ GeV}} \right)^2 \left( \frac{B_2 - B_1}{0.1} \right)
\]
First direct experimental limits on a localized WA contribution.

Submitted to PRL

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CLEO-c Expected Datasets

- \( \psi(3770) \)
  - 1000/pb
  - 2 Million tagged D mesons
  - 100 times MARKIII
- \( \sqrt{s} \) = 4170 MeV
  - 1000/pb
  - \( \sim 0.1 \) Million tagged Ds mesons
  - Scan completed.

- \( \psi(3686) \)
  - 30 million \( \psi(3686) \)
Event Shape discrimination no longer a powerful tool in the charm region.

Backgrounds at $\psi(3770)$: continuum (18 nb), $\tau$ pair (3 nb), radiative return (~1.5 nb)

$D$ meson has large branchings to low multiplicity modes.

Requiring a reconstructed $D$ provides background suppression.

$D$-Tagging removes half the event (only a single $D$ remains).

Simultaneously provides 4-vector of other $D$ meson.
$D^0 \rightarrow K^- \pi^+$

$D^0 \rightarrow K^- \pi^+ \pi^0$

$M_{bc} = \sqrt{E_{beam}^2 - P_{candidate}^2}$

$\Delta E = E_{beam} - E_{candidate}$

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Weak Annihilation: $D^+ \rightarrow \mu^+ \nu_\mu$

\[
\Gamma(D_q^+ \rightarrow l \nu) = \frac{1}{8\pi} G_F^2 M_{D_q^+} m_l^2 \left(1 - \frac{m_l^2}{M_{D_q^+}^2}\right) f_{D_q^+}^2 |V_{cq}|^2
\]

\[
\Delta M_d = 0.50 \text{ ps}^{-1} \left[ \frac{\sqrt{B_{B_d} f_{B_d}}}{200 \text{ MeV}} \right]^2 \left[ \frac{|V_{td}|}{8.8 \times 10^{-3}} \right]^2
\]

Improvement in mixing constraints with better $f_B$
Ideally one would measure $B^+ \rightarrow l^+ \nu$ (rate too low).
Realistic alternative: Measure $f_D, f_{D_s}$.

$f_D \text{ CLEO-c and } (f_B/f_D)_{\text{lattice}} \rightarrow f_B$
(And $f_D/f_{D_s}$ checks $f_B/f_{B_s}$)

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\[ D^+ \rightarrow \mu^+ \nu \]

One D fully reconstructed:

- \[ D^- \rightarrow K^+\pi^-\pi^- \]
- \[ D^- \rightarrow K^+\pi^-\pi^-\pi^0 \]
- \[ D^- \rightarrow \bar{K}^0_S\pi^- \]
- \[ D^- \rightarrow \bar{K}^0_S\pi^-\pi^-\pi^+ \]
- \[ D^- \rightarrow \bar{K}^0_S\pi^-\pi^0 \]

Require single track on other side: \( \mu \)
- PID suppresses K
- Calorimeter suppresses \( \pi^+ \)
- Require low energy in CC

Use D 4-vector to calculate missing mass (\( \sim 0 \) for \( \nu \)).
$D^+ \rightarrow \mu^+ \nu_\mu$

**Data (281 pb$^{-1}$)**

- **Mode**
  - Data: 50
  - $D^+ \rightarrow \pi^+ \pi^0$: 1.4
  - $D^+ \rightarrow K_{long} \pi^+$: 0.33
  - $D^+ \rightarrow \tau^+ \nu_\tau$: 1.08
  - Total Bck: 2.81

**Monte Carlo (1 fb$^{-1}$)**

- **Mode**
  - $K^0_L \pi^+$

- **Events Calculated**
  - $B(D^+ \rightarrow \mu^+ \nu) = (4.40 \pm 0.66^{+0.09}_{-0.12}) \times 10^{-4}$

**CLEO-c**

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

**Lattice**

- $f_{D^+} = (201 \pm 3 \pm 17)$ MeV

**References**

- PRL 95 251801 (2005)
- PRL 95 122002 (2005)

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\[ D^+ \rightarrow \tau^+ \nu_{\tau} (\tau \rightarrow \pi \nu) \]

**Data (281 pb\(^{-1}\))**

\[
\frac{\Gamma(D^+ \rightarrow \tau^+ \nu)}{\Gamma(D^+ \rightarrow \mu^+ \nu)} \neq \frac{m_\tau^2 \left(1 - m_\tau^2 / M_D^2\right)^2}{m_\mu^2 \left(1 - m_\mu^2 / M_D^2\right)^2}
\]

\[
R = \frac{\Gamma_{\text{Measured}}(D^+ \rightarrow \tau^+ \nu)}{\Gamma_{\text{SM}}(D^+ \rightarrow \tau^+ \nu)}
\]

R\(\textless 1.6 \text{ @90\%}\)

**Preliminary**

- **ANTI-CUT**
  - 8 evts

Anti-cut analysis vetoes CC energy associated with track
That is consistent with muon.

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**Motivation**

- Direct access to CKM elements ($V_{cs}, V_{cd}$)
- High resolution measurement of $q^2$ spectrum. Confronts form factor predictions.
  - Better extraction of $V_{xb}$ from exclusive semileptonic B decays.
- Opportunity for first observations.
Exclusive Semileptonic Decays

**Technique**
- D-Tag event
- Identify electron
- Reconstruct the hadronic component
- Check for consistency with neutrino

\[ U = E_{\text{miss}} - |P_{\text{miss}}| \]

**Formula**

\[ B(D^+ \rightarrow \bar{K}^0 e^+ \nu) = \frac{N(\bar{K}^0 e^+ \nu)}{\varepsilon(\bar{K}^0 e^+ \nu) N(D^-)} \]

Signal component from fit to variable \( U \)

From Monte Carlo/Data

From fit of \( M_{bc} \) and \( \Delta E \) for number of tags

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Exclusive Semileptonic Decays

Cabibbo suppressed modes

- $D^0 \rightarrow \pi^- e^+ \nu$
  - (~110 events)

- $D^0 \rightarrow \rho^- e^+ \nu$
  - (~30 events)

First Observation

Cabibbo favored modes

- $D^0 \rightarrow K^- e^+ \nu$
  - (~1400 events)

- $D^0 \rightarrow K^*^- e^+ \nu$
  - $K^*^- \rightarrow K^- \pi^0$
  - (~90 events)

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Exclusive Semileptonic Decays

Cabibbo suppressed modes:

\[ D^+ \rightarrow \pi^0 e^+ \nu \]  
(~60 events)

\[ D^+ \rightarrow \rho^0 e^+ \nu \]  
(~30 events)

Cabibbo favored modes:

\[ D^+ \rightarrow \bar{K}^0 e^+ \nu \]  
(~500 events)

\[ D^+ \rightarrow K^{0*} e^+ \nu, \quad K^{0*} \rightarrow K^- \pi^+ \]  
(~400 events)
Exclusive Semileptonic Decays

\[ D^+ \rightarrow \omega e^+ \nu \]

First Observation

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Exclusive Semileptonic Decays

Results from 57/pb

Next:
Form Factors from 281/pb
Keν and πeν
q² resolution < 0.025 GeV²
Motivation:
→ $BR(D \rightarrow X l \nu)$
→ Precision measurement of lepton momentum spectrum.
→ Compare $\Gamma_{s_l}(D^0)/\Gamma_{s_l}(D^+)$
→ Test HQT with $\Gamma_{s_l}(D^0)/\Gamma_{s_l}(D_s)$

Technique:
→ D-Tag
→ Electron ID
→ Gold DTags only
  • $K^-\pi^+$ and $K^- \pi^+\pi^+$
→ Charge correlation
Inclusive Semileptonic Decays

From 281/pb - Preliminary

\[ \mathcal{B} (D^+ \to Xe^+ \nu) = (16.13 \pm 0.20 \pm 0.34)\% \]

(\Sigma D^+ \text{ exclusive } = 15.1 \%)

\[ \mathcal{B} (D^0 \to Xe^+ \nu) = (6.46 \pm 0.17 \pm 0.12)\% \]

(\Sigma D^0 \text{ exclusive } = 6.1\%)

\[ \Gamma_{sl}(D^+)/\Gamma_{sl}(D^0) = 0.985 \pm 0.028 \pm 0.015 \]

Soon: Electron momentum shape comparison
Motivation:
- Provide most precise measurement of D hadronic BRs.
- Many current measurements determined with respect to normalizing modes (e.g. $D \rightarrow K \pi$, $D \rightarrow K \pi \pi$).
- CLEO-c will provide absolute measurements.
- Counting D mesons provides DD production cross sections.
To first order, $B$ independent of tag modes and efficiencies.

- Simultaneous fit for all BR and cross sections.
- All correlations taken into account.

Single tags: $N_i = 2N_{DD}B_i\epsilon_i$

Double tags: $N_{ij} = N_{DD}B_iB_j\epsilon_{ij}$

Syst unc cancels.

- To first order, $B$ independent of tag modes and efficiencies.
- Simultaneous fit for all BR and cross sections.
- All correlations taken into account.
Line shapes include ISR, resolution, beam energy spread. Efficiencies include FSR correction.

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Results

D⁺ Modes

- Agreement with PDG.
- PDG numbers are correlated among modes.
- CLEO-c numbers correlated.
- CLEO-c include FSR correction.

PRL 95 121801 (2005)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fitted Value (%)</th>
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<tbody>
<tr>
<td>N(D⁺D⁻)</td>
<td>(1.558±0.038±012)×10⁵</td>
</tr>
<tr>
<td>B(D⁺→K⁺π⁺π⁻)</td>
<td>(9.52±0.25±0.27) %</td>
</tr>
<tr>
<td>B(D⁺→K⁺π⁺π⁰)</td>
<td>(6.04±0.18±0.22) %</td>
</tr>
<tr>
<td>B(D⁺→K⁺π⁺)</td>
<td>(1.55±0.05±0.06) %</td>
</tr>
<tr>
<td>B(D⁺→K⁺π⁰)</td>
<td>(7.17±0.21±0.38) %</td>
</tr>
<tr>
<td>B(D⁺→K⁺π⁺π⁻⁻)</td>
<td>(3.20±0.11±0.16) %</td>
</tr>
<tr>
<td>B(D⁺→K⁺K⁻π⁺)</td>
<td>(0.97±0.04±0.04) %</td>
</tr>
</tbody>
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D⁰ Modes

Agreement with PDG.
PDG numbers are correlated among modes.
CLEO-c numbers correlated.
CLEO-c include FSR correction.
Summary

**CLEOIII**
First experimental limit on localized weak in semileptonic B decays.

**CLEO-c**
- Update on $D^+ \rightarrow \mu^+\nu$
- Limit on $D^+ \rightarrow \tau^+\nu$ (preliminary)
- Exclusive semileptonic D branchings (FF soon)
  - two “first observations”
- Inclusive semileptonic D branchings (spectrum soon)
  - Ratio for charged to neutral semileptonic widths $\sim 1$
- Absolute hadronic branchings shown.