Hadronic $D$ Decays and the $D$ Meson Decay Constant with CLEO-c

Anders Ryd, Cornell University
representing the
CLEO Collaboration
presented at the
32nd International Conference on High Energy Physics,
Beijing, China, Aug. 16-22, 2004

This presentation covers ABS11-0775 and ABS11-0776
Introduction

- I will present new, preliminary, results from CLEO-c on
  - $B f\left( D^+ \rightarrow \mu^+ \nu_\mu \right)$ and determination of $f_{D^+}$
  - absolute hadronic $D$ branching fractions, and
  - the $\sigma(e^+ e^- \rightarrow D \bar{D})$ cross section at $E_{cm} = 3.77$ GeV.

- These measurements make use of 'D-tagging', in which one $D$ is exclusively reconstructed.
  - Once we have found one $D$ we know that it recoiled against a $\bar{D}$. 
CESR-c had a pilot run Dec. '03 through Mar. '04.
  - 6 of the total of 12 wiggler magnets were installed.
  - The remaining magnets were installed this summer.
  - We recorded $57.1 \text{ pb}^{-1}$ at the $\psi(3770)$.
  - Will continue running this fall. Goal is to collect $3 \text{ fb}^{-1}$ on the $\psi(3770)$. 

1 of the 12 wiggler magnets
CLEO-c Detector

- 1 T B-field.
- New 6-layer inner drift chamber.
- Otherwise the CLEO III detector
\[ D^+ \rightarrow \mu^+ \nu_\mu \quad \text{and} \quad f_D \]

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

- A precise measurement of \( f_{D^+} \) allows precise comparison with theoretical calculations, such as lattice QCD.
- This will help determining \( f_B \), which currently can not be measured in leptonic \( B \) decays.
Charged D-Tag Reconstruction

\[ M_{BC} = \sqrt{E_{\text{beam}}^2 - |p(D)|^2} \]

\[ \Delta E = E(D) - E_{\text{beam}} \]

Require \(|\Delta E| < 20 \text{ MeV}\)

<table>
<thead>
<tr>
<th>Mode</th>
<th>( \text{Sig} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K^+\pi^-\pi^- )</td>
<td>15188</td>
</tr>
<tr>
<td>( K^+\pi^-\pi^-\pi^0 )</td>
<td>4082</td>
</tr>
<tr>
<td>( K_s\pi^- )</td>
<td>2110</td>
</tr>
<tr>
<td>( K_s\pi^-\pi^-\pi^+ )</td>
<td>3975</td>
</tr>
<tr>
<td>( K_s\pi^-\pi^-\pi^0 )</td>
<td>3297</td>
</tr>
<tr>
<td>\text{Sum}</td>
<td>28652</td>
</tr>
</tbody>
</table>

Tags where we see a small tail on the higher mass events.

\( M_D \) vs. \( M_{BC} \) for \( K^+\pi^+\pi^+ \) and \( K^-\pi^+\pi^+\pi^0 \) events. Preliminary!
Signal Extraction

- For events with $\mu$ candidate form:
  $$MM^2 = (E_{\text{beam}} - E_\mu)^2 - (\vec{p}_D - \vec{p}_\mu)^2$$
- Signal will peak at $MM^2 = m^2_\nu = 0$
- Muons are required to deposit less than 300 MeV in the calorimeter
- No additional tracks from IP
- Largest unmatched shower to be less than 250 MeV, to veto $D^+ \rightarrow \pi^+ \pi^0$

Preliminary!

8 Signal Candidates

$D^+ \rightarrow \overline{K}^0 \pi^+$

ICHEP, Beijing, Aug. 16-22, 2004   Anders Ryd, Cornell University
$D^+ \rightarrow \mu^+ \nu_\mu$ Results

8 signal candidate events with the following backgrounds

<table>
<thead>
<tr>
<th>Background</th>
<th>$\mathcal{B}$ (%)</th>
<th># of events</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^+ \rightarrow \pi^+\pi^0$</td>
<td>0.13 ± 0.02</td>
<td>0.31 ± 0.04</td>
</tr>
<tr>
<td>$D^+ \rightarrow K^0\pi^+$</td>
<td>2.77 ± 0.18</td>
<td>0.06 ± 0.05</td>
</tr>
<tr>
<td>$D^+ \rightarrow \tau^+\nu$</td>
<td>3.2 × $\mathcal{B}(D^+ \rightarrow \mu^+\nu)$</td>
<td>0.36 ± 0.08</td>
</tr>
<tr>
<td>$D^+ \rightarrow \pi^0\mu^+\nu$</td>
<td>0.31 ± 0.15</td>
<td>negligible</td>
</tr>
<tr>
<td>$D^0\bar{D}^0$</td>
<td>—</td>
<td>0.16 ± 0.16</td>
</tr>
<tr>
<td>continuum</td>
<td>—</td>
<td>0.17 ± 0.17</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1.07 ± 0.25</td>
</tr>
</tbody>
</table>

Due to simulation uncertainties we take background as 1.07 ± 1.07

With 28575 $D^+$ tags and an efficiency of 69.9% for signal events to satisfy the selection criteria given a $D^+$ tag we obtain:

$Bf(D^+ \rightarrow \mu^+\nu) = (3.5 ± 1.4 ± 0.6) \times 10^{-4}$

$f_{D^+} = (201 ± 41 ± 17)$ MeV

Theoretical predictions for $f_D$ are in the range 190 to 260 MeV.
Hadronic $D$ Decays and $\sigma (e^+ e^- \rightarrow D \overline{D})$

- In order to measure the cross section and absolute branching fractions we need to determine the number of produced $DD\overline{D}$ events
  - Use a 'double tag' technique, pioneered by MARK III

$$N_i = 2 \epsilon_i B_i N_{DD\overline{D}}, \quad N_{DD\overline{D}} = \frac{N_i^2 \epsilon_{ii}}{4N_{ii} \epsilon_i^2}$$

- Use 3 $D^0$ modes ($K\pi^+, K^+\pi^0, K^-\pi^+\pi^-\pi^+$) and 2 $D^+$ modes ($K\pi^+\pi^+, K_s\pi^+$)
- Determine separately the $D$ and $\overline{D}$ yields
  - This gives 10 single tag yields and 13 ($=3^2+2^2$) double tag yields
  - In a combined $\chi^2$ fit we extract 5 branching fractions and $D^0\overline{D}^0$ and $D^+D^- \overline{D}^0$ yields. The fit includes the systematic errors.
  - Many systematics cancel in the $DD\overline{D}$ yields.
## Single Tag Yields

<table>
<thead>
<tr>
<th>$D$ or $\bar{D}$ Mode</th>
<th>Yield ($10^3$)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^0 \rightarrow K^-\pi^+$</td>
<td>5.14 ± 0.07</td>
<td>65.1 ± 0.6</td>
</tr>
<tr>
<td>$\bar{D}^0 \rightarrow K^+\pi^-$</td>
<td>5.16 ± 0.08</td>
<td>66.3 ± 0.6</td>
</tr>
<tr>
<td>$D^0 \rightarrow K^-\pi^+\pi^0$</td>
<td>9.62 ± 0.12</td>
<td>33.6 ± 0.4</td>
</tr>
<tr>
<td>$\bar{D}^0 \rightarrow K^+\pi^-\pi^0$</td>
<td>9.58 ± 0.12</td>
<td>34.0 ± 0.4</td>
</tr>
<tr>
<td>$D^0 \rightarrow K^-\pi^+\pi^-\pi^-$</td>
<td>7.39 ± 0.10</td>
<td>45.1 ± 0.5</td>
</tr>
<tr>
<td>$\bar{D}^0 \rightarrow K^+\pi^-\pi^-\pi^+$</td>
<td>7.39 ± 0.10</td>
<td>45.5 ± 0.5</td>
</tr>
<tr>
<td>$D^+ \rightarrow K^-\pi^+\pi^+$</td>
<td>7.58 ± 0.09</td>
<td>52.2 ± 0.5</td>
</tr>
<tr>
<td>$D^- \rightarrow K^+\pi^-\pi^-$</td>
<td>7.57 ± 0.09</td>
<td>51.9 ± 0.5</td>
</tr>
<tr>
<td>$D^+ \rightarrow K^0_S\pi^+$</td>
<td>1.09 ± 0.04</td>
<td>45.6 ± 0.5</td>
</tr>
<tr>
<td>$D^- \rightarrow K^0_S\pi^-$</td>
<td>1.12 ± 0.04</td>
<td>45.9 ± 0.5</td>
</tr>
</tbody>
</table>

Preliminary!
Fits for Double Tag Yields

\[ m(D) \quad (GeV/c^2) \]

- 2-D fit for double tag yields
- Fit includes correlations due to beam energy fluctuations and ISR.
Double Tag Yields

**Table III: Double tag data yields and efficiencies and their statistical uncertainties**

<table>
<thead>
<tr>
<th>$D$ Mode</th>
<th>$\bar{D}$ Mode</th>
<th>Yield ($10^2$)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^0 \to K^-\pi^+$</td>
<td>$\bar{D}^0 \to K^+\pi^-$</td>
<td>$1.09 \pm 0.11$</td>
<td>$42.6 \pm 0.5$</td>
</tr>
<tr>
<td>$D^0 \to K^-\pi^+\pi^0$</td>
<td>$\bar{D}^0 \to K^+\pi^-\pi^0$</td>
<td>$4.84 \pm 0.23$</td>
<td>$12.1 \pm 0.3$</td>
</tr>
<tr>
<td>$D^0 \to K^-\pi^+\pi^+\pi^-$</td>
<td>$\bar{D}^0 \to K^+\pi^-\pi^-\pi^+$</td>
<td>$2.80 \pm 0.17$</td>
<td>$20.8 \pm 0.4$</td>
</tr>
<tr>
<td>$D^0 \to K^-\pi^+$</td>
<td>$\bar{D}^0 \to K^+\pi^-\pi^0$</td>
<td>$2.45 \pm 0.16$</td>
<td>$23.2 \pm 0.4$</td>
</tr>
<tr>
<td>$D^0 \to K^-\pi^+\pi^0$</td>
<td>$\bar{D}^0 \to K^+\pi^-$</td>
<td>$2.62 \pm 0.16$</td>
<td>$22.6 \pm 0.4$</td>
</tr>
<tr>
<td>$D^0 \to K^-\pi^+$</td>
<td>$\bar{D}^0 \to K^+\pi^-\pi^-\pi^+$</td>
<td>$2.05 \pm 0.14$</td>
<td>$29.6 \pm 0.4$</td>
</tr>
<tr>
<td>$D^0 \to K^-\pi^+\pi^+\pi^-$</td>
<td>$\bar{D}^0 \to K^+\pi^-\pi^0$</td>
<td>$1.97 \pm 0.14$</td>
<td>$29.6 \pm 0.4$</td>
</tr>
<tr>
<td>$D^0 \to K^-\pi^+\pi^0$</td>
<td>$\bar{D}^0 \to K^+\pi^-\pi^-\pi^+$</td>
<td>$3.59 \pm 0.20$</td>
<td>$15.2 \pm 0.3$</td>
</tr>
<tr>
<td>$D^0 \to K^-\pi^+\pi^+\pi^-$</td>
<td>$\bar{D}^0 \to K^+\pi^-\pi^0$</td>
<td>$3.40 \pm 0.19$</td>
<td>$15.5 \pm 0.3$</td>
</tr>
<tr>
<td>$D^+ \to K^-\pi^+\pi^+$</td>
<td>$D^- \to K^+\pi^-\pi^-$</td>
<td>$3.79 \pm 0.20$</td>
<td>$26.7 \pm 0.4$</td>
</tr>
<tr>
<td>$D^+ \to K_S^0\pi^+$</td>
<td>$D^- \to K_S^0\pi^-$</td>
<td>$0.090 \pm 0.030$</td>
<td>$20.6 \pm 0.4$</td>
</tr>
<tr>
<td>$D^+ \to K^-\pi^+\pi^+$</td>
<td>$D^- \to K_S^0\pi^-$</td>
<td>$0.609 \pm 0.079$</td>
<td>$23.7 \pm 0.4$</td>
</tr>
<tr>
<td>$D^+ \to K_S^0\pi^+$</td>
<td>$D^- \to K^+\pi^-\pi^-$</td>
<td>$0.530 \pm 0.073$</td>
<td>$23.9 \pm 0.4$</td>
</tr>
</tbody>
</table>

- 2480 neutral double tags
- 502 charged double tags

Preliminary!
Systematics

<table>
<thead>
<tr>
<th>Source</th>
<th>Fractional Uncertainty (%)</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data processing</td>
<td>0.3</td>
<td>All yields</td>
</tr>
<tr>
<td>Yield fit functions</td>
<td>0.1–2.9</td>
<td>All yields</td>
</tr>
<tr>
<td>Background bias</td>
<td>2.5</td>
<td>DT yields</td>
</tr>
<tr>
<td>Double DCSD interference</td>
<td>0.8</td>
<td>Neutral DT yields</td>
</tr>
<tr>
<td>Detector simulation</td>
<td>3.0</td>
<td>Tracking efficiencies</td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td>$K_S^0$ efficiencies</td>
</tr>
<tr>
<td></td>
<td>4.4</td>
<td>$\pi^0$ efficiencies</td>
</tr>
<tr>
<td></td>
<td>0.3</td>
<td>$\pi^{\pm}$ PID efficiencies</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
<td>$K^{\pm}$ PID efficiencies</td>
</tr>
<tr>
<td>Trigger simulation</td>
<td>0.3</td>
<td>ST efficiencies</td>
</tr>
<tr>
<td>Final state radiation</td>
<td>0.5</td>
<td>$D$ efficiencies</td>
</tr>
<tr>
<td>$</td>
<td>\Delta E</td>
<td>$ requirement</td>
</tr>
<tr>
<td>Resonant substructure</td>
<td>3.0</td>
<td>$D^0 \rightarrow K^-\pi^+\pi^+\pi^-$ efficiencies</td>
</tr>
</tbody>
</table>

- Background bias
  - Currently dominated by tracking efficiency systematics
  - We have a 3%/track correction to the MC tracking efficiency
  - Most systematics will improve with more data
Preliminary Fit Results

and systematic, respectively.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fitted Value</th>
<th>PDG 2004*</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{D^0 \bar{D}^0}$</td>
<td>(1.98 ± 0.04 ± 0.03) × 10^5</td>
<td></td>
</tr>
<tr>
<td>$\mathcal{B}(D^0 \rightarrow K^- \pi^+)$</td>
<td>0.0392 ± 0.0008 ± 0.0023</td>
<td>0.0380 ± 0.0009</td>
</tr>
<tr>
<td>$\mathcal{B}(D^0 \rightarrow K^- \pi^+ \pi^0)$</td>
<td>0.143 ± 0.003 ± 0.010</td>
<td></td>
</tr>
<tr>
<td>$\mathcal{B}(D^0 \rightarrow K^- \pi^+ \pi^+ \pi^-)$</td>
<td>0.081 ± 0.002 ± 0.009</td>
<td></td>
</tr>
<tr>
<td>$N_{D^+ D^-}$</td>
<td>(1.48 ± 0.06 ± 0.04) × 10^5</td>
<td></td>
</tr>
<tr>
<td>$\mathcal{B}(D^+ \rightarrow K^- \pi^+ \pi^+)$</td>
<td>0.098 ± 0.004 ± 0.008</td>
<td>0.092 ± 0.006</td>
</tr>
<tr>
<td>$\mathcal{B}(D^+ \rightarrow K_S^0 \pi^+)$</td>
<td>0.0161 ± 0.0008 ± 0.0015</td>
<td>1.96 ± 0.06</td>
</tr>
</tbody>
</table>

The results of the data fit are shown in Table V. The $\chi^2$ of the

*Our branching fractions are corrected for FSR, PDG values are not.

Using our measured luminosity of $57.2 ± 1.7$ pb$^{-1}$ we obtain:

$\sigma(D^0 \bar{D}^0) = (3.47 ± 0.07 ± 0.15)$ nb  \hspace{1cm} $\sigma(D^+ D^-) = (2.59 ± 0.11 ± 0.11)$ nb

$\sigma(D \bar{D}) = (6.06 ± 0.13 ± 0.22)$ nb
Conclusions

• CLEO-c has taken ~60 pb\(^{-1}\) of pilot data at the \(\psi(3770)\)
  • The full compliment of wigglers has been installed, and data taking will resume this fall.
• Using this sample we have obtained the preliminary results
  • \(Bf(D^+ \rightarrow \mu^+ \nu) = (3.5 \pm 1.4 \pm 0.6) \times 10^{-4}\) \(f_{D^-} = (201 \pm 41 \pm 17)\) MeV
  • \(Bf(D^0 \rightarrow K^+ \pi^-) = (3.92 \pm 0.08 \pm 0.23)\) % \(Bf(D^+ \rightarrow K^- \pi^+ \pi^+) = (9.8 \pm 0.4 \pm 0.8)\) %
  • At \(E_{cm} = 3.773\) GeV we measured the e\(^+\)e\(^-\) cross sections
    • \(\sigma(D^0 \overline{D}^0) = (3.47 \pm 0.07 \pm 0.15)\) nb \(\sigma(D^+ \overline{D}^-) = (2.59 \pm 0.11 \pm 0.11)\) nb
    • \(\sigma(D \overline{D}) = (6.06 \pm 0.13 \pm 0.22)\) nb
• Using all tagging modes we have a \(D\)-tagging efficiency of 25%.
• Look forward to many more results from CLEO-c in the near future as we continue to take data at charm threshold.