Recent Charm Results from CLEO-c

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The CLEO detector is taking data at the CESR symmetric $e^+e^-$ collider operating as a charm factory since 2003

Main physics scope:

- Provide important test and validation of strong interaction (QCD) theory in the charm sector
- Precise charm measurements are critical to extract weak physics from observables (precision CKM measurements)
- Other exciting physics possibilities (even search for new physics)
Selected topics
Very diverse physics topics at CLEO: D, D_s, c\bar{c}, b\bar{b} etc.

- **D^0, D^+, and D_s** hadronic decays
  - absolute BF are important to normalize D decays and for precision B measurements
  - help to understand strong (final state) interactions better

- **D^+ and D_s** purely leptonic decays and $f_{D(s)}$
  - test non-perturbative QCD (especially Lattice QCD) calculations of $f_{D(s)}$
  - helps to determine CKM matrix elements $|V_{td}|$, $|V_{ts}|$

- **Spectroscopy: D^0 mass and $\chi_{cJ}$ 3-body decays**
  - help with interpretation of X(3872) charmonium-like state;
  - light meson spectroscopy
**CLEO-c detector and data**

- Excellent tracking, calorimetry, and particle ID
- Changes from CLEO III:
  - Si vertex detector replaced by 6-layer inner drift chamber
  - Magnetic field: 1.0 T (from 1.5 T)
- 3 million $\psi(2S)$ events
- 281 pb$^{-1}$ DD
- 314 pb$^{-1}$ $D_s^*D_s$
- 60 pb$^{-1}$ scan: 3.97–4.26 GeV
Absolute Charm Meson Branching Fractions

$D^0$ and $D^+$ hadronic Branching Fractions

PRL 95, 121801 (2005) with 56 pb$^{-1}$ $D\bar{D}$ data

Preliminary results with 281 pb$^{-1}$ data presented here

$D_s$ hadronic Branching Fractions

Preliminary results with 195 pb$^{-1}$ $D_s^*D_s$ data:

CLEO CONF 06-13 (hep-ex/0607079)
Tagging technique

- **DD production at threshold:**
  no extra particles, low multiplicity, very clean final state

- **Use tagging technique** (pioneered by Mark III) to fully reconstruct one (single tag) or both (double tag) \(D\) - greatly reduces combinatoric background

- **Variables used in the tag reconstruction:**
  \[
  \Delta E = E_{D-\text{tag}} - E_{\text{beam}} \approx 0
  \]
  \[
  M_{bc} = \sqrt{E_{\text{beam}}^2 - P_{D-\text{tag}}^2} \approx M_D
  \]

**Single tags**
- \(D^+ \rightarrow K^- \pi^+ \pi^+\)
- \(D^- \rightarrow K^+ \pi \pi^-\)
  \(~81K~\) events

**PRELIMINARY**

- Cut on \(\Delta E (\pm 3\delta)\) and use \(M_{bc}\) to extract the signal by fitting

- All single tags in 281 pb\(^{-1}\):
  - \(D^0D^0\): \(~230K~\)
  - \(D^+D^-\): \(~170K~\)
**D^0 and D^+ absolute BF: method**

- Measure 3 D^0 and 6 D^+ decay modes
  
  \[ n_i = N_{DD}B_i \varepsilon_i \]
  
  \[ n_{ij} = N_{DD}B_iB_j \varepsilon_{ij} \]
  
  \[ B_i \approx \frac{n_{ij} \varepsilon_j}{n_j \varepsilon_{ij}} \]
  
  \[ N_{DD} \approx \frac{n_i n_j \varepsilon_{ij}}{n_{ij} \varepsilon_i \varepsilon_j} \]

BF are independent of luminosity and cross section

- Combine ST and DT yields for all modes in \( \chi^2 \) fit to get absolute BF (and \( N_{DD} \))

Scale of statistical error is set by number of total DT yield

Since \( \varepsilon_{ij} \approx \varepsilon_i \varepsilon_j \) to first order

\[ B_i \text{ are independent of tag mode efficiencies (} \varepsilon_j \) \]
**D⁰ and D⁺ absolute BF: results**

- Absolute BF's based on 56 pb⁻¹ data are published (and included in PDG06)
- Updating the results with 281 pb⁻¹

**Statistical error ~1-2%, systematics limited**
(working on some improvements)

**BF corrected for FSR** (up to 2% effect)

- **D⁰ → K⁻π⁺**
- **D⁺ → K⁻π⁺π⁺**

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Value ± Error 1</th>
<th>Error 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>K⁻π⁺π⁰</td>
<td>14.6 ± 0.1 ± 0.4</td>
<td></td>
</tr>
<tr>
<td>K⁻π⁺π⁻π⁺</td>
<td>8.3 ± 0.1 ± 0.3</td>
<td></td>
</tr>
<tr>
<td>K⁻π⁺π⁺π⁺</td>
<td>9.2 ± 0.1 ± 0.3</td>
<td></td>
</tr>
<tr>
<td>K⁻π⁺π⁺π⁰</td>
<td>6.0 ± 0.1 ± 0.2</td>
<td></td>
</tr>
<tr>
<td>K₀π⁺</td>
<td>1.55 ± 0.02 ± 0.05</td>
<td></td>
</tr>
<tr>
<td>K₀π⁺π⁰</td>
<td>7.2 ± 0.1 ± 0.3</td>
<td></td>
</tr>
<tr>
<td>K₀π⁺π⁻π⁺</td>
<td>3.13 ± 0.05 ± 0.14</td>
<td></td>
</tr>
<tr>
<td>K⁻K⁺π⁺</td>
<td>0.93 ± 0.02 ± 0.03</td>
<td></td>
</tr>
</tbody>
</table>

**Preliminary**

\[ \delta B/B \approx 2.3\% \]

\[ \delta B/B \approx 2.9\% \]
D_s absolute BF

- scanned the region to maximize D_s production (12 energy points):
  - maximum cross section at 4.170 GeV
  - almost exclusively D_s*D_s: \( \sigma \approx 0.9 \) nb
    compare to max \( \sigma(D_sD_s) \approx 0.3 \) nb only
- D_s*D_s has different kinematics than DD:
  D_s from D_s*\( \rightarrow (\gamma, \pi^0)D_s \) has smeared momenta
    (the \( \gamma \) or \( \pi^0 \) is not reconstructed)

M_{inv} vs. M_{bc} for K^-K^+\pi^+ candidates in MC

Cut on \( M_{bc} \) and use \( M_{inv} \) to extract D_s yields

Direct D_s
**D_s absolute BF**

- Measure 6 D_s decay modes with similar technique to DD analysis

<table>
<thead>
<tr>
<th>Mode</th>
<th>D_s^+</th>
<th>D_s^-</th>
</tr>
</thead>
<tbody>
<tr>
<td>K^- K^+</td>
<td>1055±39</td>
<td>928±37</td>
</tr>
<tr>
<td>K^- K^+ π^+</td>
<td>4316±89</td>
<td>4350±89</td>
</tr>
<tr>
<td>K^- K^- π^+</td>
<td>1160±85</td>
<td>1251±84</td>
</tr>
<tr>
<td>π^- π^- π^-</td>
<td>970±80</td>
<td>947±78</td>
</tr>
<tr>
<td>η^- π^-</td>
<td>547±50</td>
<td>570±50</td>
</tr>
<tr>
<td>η'^- π^-</td>
<td>362±23</td>
<td>372±24</td>
</tr>
</tbody>
</table>

Single tag yields are determined from fit to \( M_{inv} \) (double Gaussian or Crystal Ball function plus linear background.)

PRELIMINARY

Double tag yields are determined via side-band subtraction in \( M(D_s^+) - M(D_s^-) \) projection.

All D_s double tags combined in 195 pb\(^{-1}\): 518 - 47 (backgr.)
**Ds absolute BF: results in 195 pb⁻¹**

- Binned max likelihood fit to all modes simultaneously
- Errors are already less than PDG
- Ds→φπ is critical (used to normalize other Ds decays) but difficult: scalar f₀(980) or a₀(980) contribution (E687 and FOCUS)

BF depends on choice of cuts

**Partial Ds→K⁺K⁻π⁺ branching fraction:**

- M(φ) ± 10 MeV/c²: 1.98 ± 0.12 ± 0.09 %
- M(φ) ± 20 MeV/c²: 2.25 ± 0.13 ± 0.12 %

(δB/B ≈ 8%)

**PDG06:** B(Ds→φπ)xB(φ→KK) = 2.16 ± 0.28% (δB/B ≈ 13%)

(not exactly comparable b/c different cuts!)
D$^+$ and D$_s$ leptonic decays and decay constants

D$^+ \rightarrow \mu^+ \nu$ and $f_D$:

PRL 95, 251801 (2005): $D^+ \rightarrow \mu^+ \nu$ BF and $D^+ \rightarrow e^+ \nu$ UL
PRD 73, 112005 (2006): $D^+ \rightarrow \tau^+ \nu$ UL
with 281 pb$^{-1}$ D$D$ data

D$_s \rightarrow \mu^+ \nu$ and $\tau^+(\pi^+ \nu)\nu$:

CLEO CONF 06-17 (hep-ex/0607074) with 195 pb$^{-1}$
Preliminary results with 314 pb$^{-1}$ D$_s^*D_s$ data

D$_s \rightarrow \tau^+(e^+ \nu \nu)\nu$:

Preliminary results with 195 pb$^{-1}$ D$_s^*D_s$ data
**$D_{(s)} \rightarrow \ell^+ \nu$: Motivation**

- Using $V_{cd}$ and $V_{cs}$, $f_D$ and $f_{Ds}$ can be determined from $D_{(s)} \rightarrow \ell^+ \nu$ purely leptonic decays.

\[ \Gamma(P \rightarrow \ell \nu) = \frac{G_F^2}{8\pi} |V_{qq'}|^2 f_P^2 m^2 \left( 1 - \frac{m^2}{M_P^2} \right)^2 \]

- $V_{qq'}$: CKM matrix element (weak interaction)
- $f_P$: pseudoscalar decay constant (strong interaction between quarks)

- Measurement of $f_{D(s)}$ help to calibrate and validate Lattice QCD.

- Impact on heavy flavor physics to constrain the CKM matrix: validated (L)QCD can calculate $f_B$ ($f_{Bs}$) to determine $|V_{td}|$ ($|V_{ts}|$) from $B^0$ ($B_s$) mixing (very hard to measure since $B^+ \rightarrow \ell^+ \nu$ BF is very small and $|V_{ub}|$ has large, ~15%, uncertainty)

- New physics: relative decay rate to different lepton flavors can be modified by other particle contributions (e.g. Higgs)

\[
\begin{align*}
D^+ &\rightarrow \ell^+ \nu: & \Gamma(e^+ \nu) : \Gamma(\mu^+ \nu) : \Gamma(\tau^+ \nu) &= 2.3 \times 10^{-5} : 1.0 : 2.7 \\
D_s &\rightarrow \ell^+ \nu: & \Gamma(e^+ \nu) : \Gamma(\mu^+ \nu) : \Gamma(\tau^+ \nu) &= 2.5 \times 10^{-5} : 1.0 : 9.7
\end{align*}
\]

*in SM*
**Measurement of $D^+ \rightarrow \mu^+ \nu$ and $f_D$**

**Tag side**

$e^+e^- \rightarrow \psi(3770) \rightarrow D^-D^+$

- **Reconstruct $D^-$ in six decay modes**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^+ \pi^- \pi^-$</td>
<td>77387 ± 281</td>
</tr>
<tr>
<td>$K^+ \pi^- \pi^- \pi^0$</td>
<td>24850 ± 214</td>
</tr>
<tr>
<td>$K_S \pi^-$</td>
<td>11162 ± 136</td>
</tr>
<tr>
<td>$K_S \pi^- \pi^- \pi^+$</td>
<td>18176 ± 225</td>
</tr>
<tr>
<td>$K_S \pi^- \pi^0$</td>
<td>20244 ± 170</td>
</tr>
<tr>
<td>$K^+ K^- \pi^-$</td>
<td>6535 ± 95</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td>158354 ± 496</td>
</tr>
</tbody>
</table>

**Signal side**

- A single muon candidate ($E_{CC} < 300$ MeV)
- No extra track or shower with $E_{CC} > 250$ MeV

**Calculate missing mass**

$$MM^2 = (E_{beam} - E_{\mu})^2 - (\vec{p}_{tag} - \vec{p}_{\mu})^2$$

- **281 pb$^{-1}$**

**All six modes**

- **50 $D^+ \rightarrow \mu^+ \nu$ candidates** (2.8 background events)

**$B(D^+ \rightarrow \mu^+ \nu) = (4.4 \pm 0.7 \pm 0.1) \times 10^{-4}$**

**$f_D = (222.6 \,^{+2.8}_{-3.4})$ MeV**

(δf/f ~ 8%)
\[ \text{Ds} \rightarrow \mu^+ \nu \text{ and } \tau^+(\pi^+ \nu)\nu \] (1)

- At \( E_{\text{cm}} = 4170 \text{ MeV} \): use \( e^+e^- \rightarrow \text{Ds}^*\text{Ds} \rightarrow \gamma\text{DsDs} \) \( [\text{B} (\text{Ds}^* \rightarrow \gamma\text{Ds}) \approx 94\%] \)

- Reconstruct one Ds decaying into 8 hadronic modes (tag)

- Require an additional photon and calculate recoil mass against the \( \gamma\text{Ds-tag} \)

(Kinematic constraints are used to improve resolutions and remove multiple combinations)

\[ M_{\text{rec}}^2 = (E_{\text{CM}} - E_{\text{Ds-tag}} - E_{\gamma})^2 - (-p_{\text{Ds-tag}} - \gamma p_{\gamma})^2 \approx M_{\text{Ds}} \]

\(~31.3K\ Ds \text{ tags in 314 pb}^{-1}\)

\(~18.6K\ \gamma\text{Ds tags in signal region (314 pb}^{-1}\)

(PRELIMINARY)
$D_s \rightarrow \mu^+\nu$ and $\tau^+(\pi^+\nu)\nu$ (2)

- Require one additional track and no extra shower in CC with > 300 MeV
- Calculate missing mass in the event to infer the neutrino(s):

$$MM^2 = \left( E_{CM} - E_{D_s-tag} - E_\gamma - E_{\mu(\pi)} \right)^2 - \left( -p_{D_s-tag} - p_\gamma - p_\mu \right)^2$$

Note different scale

PRELIMINARY
$D_s \rightarrow \mu^+\nu$ and $\tau^+(\pi^+\nu)\nu$ (3)

- Three cases depending on particle type:

  **A**: 92 events (3.5 backg+7.4 $\tau^+(\pi^+\nu)\nu$) using SM $\tau/\mu$ ratio
  \[
  B(D_s \rightarrow \mu^+\nu) = (0.594 \pm 0.066 \pm 0.031)\%
  \]

  **B+C**: 31+25 events (3.5+5 backg)
  \[
  B(D_s \rightarrow \tau^+\nu) = (8.0 \pm 1.3 \pm 0.4)\%
  \]

  **A+B+C**: 148 events (10.7 background) using SM $\tau/\mu$ ratio
  \[
  B^{eff}(D_s \rightarrow \mu^+\nu) = (0.621 \pm 0.058 \pm 0.032)\%
  
  f_{Ds} = (270 \pm 13 \pm 7) \text{ MeV}
  \]

  \[
  B(D_s \rightarrow e^+\nu) < 1.3 \times 10^{-4}
  \]

  **Data 314 pb$^{-1}$**

  Track consistent with $\mu^+$
  (E$_{CC} < 300$ MeV)

  mostly $D_s \rightarrow \mu^+\nu$

  accepts 99% of $\mu^+$ and 60% of $\pi^+$

  31 events

  Track consistent with $\pi^+$
  (E$_{CC} > 300$ MeV)

  accepts 1% of $\mu^+$ and 40% of $\pi^+$

  mostly $D_s \rightarrow \tau^+(\pi^+\nu)\nu$

  25 events

  Track consistent with $e^+$

  PRELIMINARY
\[ D_s \rightarrow \tau^+(e^+\nu\nu)\nu \]

- Complimentary analysis using \( D_s \rightarrow \tau^+\nu \), \( \tau^+ \rightarrow e^+\nu\nu \)

\[ B(D_s \rightarrow \tau^+\nu)B(\tau^+ \rightarrow e^+\nu\nu) \approx 1.3\% \text{ significant} \ [\text{compare to } B(D_s \rightarrow Xe^+\nu) \approx 8\%] \]

**Analysis technique:**
- Find \( D_s^- \) tag and \( e^+ \) (no need to find \( \gamma \) from \( D_s^* \))
- No extra track
- Extra energy in CC < 400 MeV

**Results:**
\[ B(D_s \rightarrow \tau^+\nu) = (6.29 \pm 0.78 \pm 0.52)\% \]
[PDG06: \( B(D_s \rightarrow \tau^+\nu) = (6.4 \pm 1.5)\% \)]
\[ f_{D_s} = (278 \pm 17 \pm 12) \text{ MeV} \]


**$f_D$ and $f_{Ds}$ : comparison with theory**

- **Summary of CLEO-c results:**
  
  \[
  f_D = (223 \pm 17 \pm 3) \text{ MeV} \\
  f_{Ds} = (273 \pm 10 \pm 5) \text{ MeV}
  \]
  
  ($f_{Ds}$ weighted average of the two methods - syst. error is mostly uncorrelated)

  \[
  f_{Ds}/f_D = 1.22 \pm 0.09 \pm 0.03
  \]

- **Consistent with most models**
- **Statistically limited** – more data is on the way!
- **Lattice QCD (unquenched)**
  
  PRL 95, 122002 (2005):

  \[
  f_D = (201 \pm 3 \pm 17) \text{ MeV} \\
  f_{Ds} = (249 \pm 3 \pm 16) \text{ MeV}
  \]

  \[
  f_{Ds}/f_D = 1.24 \pm 0.01 \pm 0.07
  \]

  *systematics limited!*

**PRELIMINARY**
Spectroscopy

\[ D^0 \text{ mass measurement} \text{ and } X(3872) \]

PRL 98, 092002 (2007)
with 281 pb\(^{-1}\) D\(\bar{D}\) data

\[ \chi_c \rightarrow h^+h^-h^0 \text{ decays} \]

PRD 75, 032002 (2007)
using 3 million \(\psi(2S)\) decays
Precise D⁰ mass measurement

Relevant to interpretation of X(3872): D⁰D⁰* molecule?

\[ e^+e^- \rightarrow \Psi(3770) \rightarrow \overline{D^0}D^0 \]
\[ \text{tag} \rightarrow K_s(\pi^+\pi^-)\varphi(K^+K^-) \]

- \( K \) and \( \pi \) has small momenta: \( \delta p/p \) is small
- \( K_s \) mass is constrained
- Use inclusive \( K_s \rightarrow \pi^+\pi^- \) and \( J/\psi \rightarrow \mu^+\mu^- \) decays to precisely calibrate D⁰ mass

\[ M(K_s) = 497.648 \pm 0.007 \pm 0.037 \text{ MeV/c}^2 \]

PDG06: 497.648 ± 0.022 MeV/c²

\[ M(D^0) = 1864.847 \pm 0.150 \pm 0.095 \text{ MeV/c}^2 \]

PDG06(ave.): 1864.1 ± 1.0 MeV/c²
PDG06(fit): 1864.5 ± 0.4 MeV/c²

Binding energy of X(3872) as \( D^0D^0* \) molecule:

\[ \Delta E_b = M_{D^0D^0*} - M_{X(3872)} = (2M_{D^0} + \Delta M_{D^0*-D^0}) - M_{X(3872)} \]

\[ = +0.6 \pm 0.6 \text{ MeV} \]

error is now limited by \( \delta M_{X(3872)} \)

D⁰D⁰* molecule, other 4-quark state with small binding energy, or threshold cusp?
\(\chi_c \rightarrow h^+h^-h^0\) decays

- \(\chi_{cJ}\) production from \(\psi(2S)\) via radiative decay:
  \[e^+e^- \rightarrow \psi(2S) \rightarrow \gamma\chi_{cJ}\ (J=0,1,2)\]
  \[N[\psi(2S)] \approx 3M\quad\text{CLEO III+c}\]
  \[B[\psi(2S)\rightarrow\gamma\chi_{cJ}] \approx 9\%\quad\text{(for each J)}\]

- Motivation for studying \(\chi_{cJ}\) decay
  - Hadronic decays are not well known
  - Complimentary information on light hadrons and possible glueball dynamics (besides \(J/\psi\) and \(\psi(2S)\) decays)

Study 8 exclusive 3-body final states – most of them are first observations:

<table>
<thead>
<tr>
<th>Mode</th>
<th>(\chi_{c0})</th>
<th>(\chi_{c1})</th>
<th>(\chi_{c2})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\pi^+\pi^-\eta)</td>
<td>&lt; 0.21</td>
<td>5.0 ± 0.3 ± 0.4 ± 0.3</td>
<td>0.49 ± 0.12 ± 0.05 ± 0.03</td>
</tr>
<tr>
<td>(K^+K^-\eta)</td>
<td>&lt; 0.24</td>
<td>0.34 ± 0.10 ± 0.03 ± 0.02</td>
<td>&lt; 0.33</td>
</tr>
<tr>
<td>(p\bar{p}\eta)</td>
<td>0.39 ± 0.11 ± 0.04 ± 0.02</td>
<td>&lt; 0.16</td>
<td>0.19 ± 0.07 ± 0.02 ± 0.01</td>
</tr>
<tr>
<td>(\pi^+\pi^-\eta')</td>
<td>&lt; 0.38</td>
<td>2.4 ± 0.4 ± 0.2 ± 0.2</td>
<td>0.51 ± 0.18 ± 0.05 ± 0.03</td>
</tr>
<tr>
<td>(K^+K^-\pi^0)</td>
<td>&lt; 0.06</td>
<td>1.95 ± 0.16 ± 0.18 ± 0.14</td>
<td>0.31 ± 0.07 ± 0.03 ± 0.02</td>
</tr>
<tr>
<td>(p\bar{p}\pi^0)</td>
<td>0.59 ± 0.10 ± 0.07 ± 0.03</td>
<td>0.12 ± 0.05 ± 0.01 ± 0.01</td>
<td>0.44 ± 0.08 ± 0.04 ± 0.03</td>
</tr>
<tr>
<td>(\pi^+K^-\bar{K}^0)</td>
<td>&lt; 0.10</td>
<td>8.1 ± 0.6 ± 0.6 ± 0.5</td>
<td>1.3 ± 0.2 ± 0.1 ± 0.1</td>
</tr>
<tr>
<td>(K^+\bar{p}\Lambda)</td>
<td>1.07 ± 0.17 ± 0.10 ± 0.06</td>
<td>0.33 ± 0.09 ± 0.03 ± 0.02</td>
<td>0.85 ± 0.14 ± 0.08 ± 0.06</td>
</tr>
</tbody>
</table>
$\chi_c \rightarrow h^+ h^- h^0$ decays

Statistics in $\chi_{c1} \rightarrow \pi^+ \pi^- \eta$, $K^+ K^- \pi^0$, $K_s K^- \pi^+$ sufficient for Dalitz analysis of resonant substructure (next two slides)
Dalitz analysis: $\chi_{c1} \rightarrow \pi^+ \pi^- \eta$

- Small statistics (228 events): simple model with non-interfering resonances
- Contributions from $a_0(980)\pi$, $f_2(1270)\eta$, $\sigma\eta$

<table>
<thead>
<tr>
<th>Mode</th>
<th>$a_R$</th>
<th>Fit fraction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_0(980)^\pm \pi^\mp$</td>
<td>1</td>
<td>75.1 ± 3.5 ± 4.3</td>
</tr>
<tr>
<td>$f_2(1270)\eta$</td>
<td>0.103 ± 0.014 ± 0.005</td>
<td>14.4 ± 3.1 ± 1.9</td>
</tr>
<tr>
<td>$\sigma\eta$</td>
<td>0.41 ± 0.05 ± 0.10</td>
<td>10.5 ± 2.4 ± 1.2</td>
</tr>
</tbody>
</table>

- May offer the best way to determine $a_0(980)$ parameters with more statistics
- ~8 times more data collected (not yet analyzed)
Dalitz analysis: $\chi_{c1} \rightarrow K^+K^-\pi^0/K_sK^-\pi^+$

- Combined analysis (using isospin symmetry)
- Contributions from $K^*(892)K$, $K^*(1430)K$, $a_0(980)\pi$
- Additional $\kappa K$ or non-resonant component does not improve the fit
- Need more data to do a complete PW analysis including interference

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<th>Fit fraction (%)</th>
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<td>$K^*(892)K$</td>
<td>1</td>
<td>31.4 ± 2.2 ± 1.7</td>
</tr>
<tr>
<td>$K_0^*(1430)K$</td>
<td>3.8 ± 0.4 ± 0.2</td>
<td>30.4 ± 3.5 ± 3.7</td>
</tr>
<tr>
<td>$K_2^*(1430)K$</td>
<td>0.44 ± 0.06 ± 0.04</td>
<td>23.1 ± 3.4 ± 7.1</td>
</tr>
<tr>
<td>$a_0(980)\pi$</td>
<td>6.1 ± 0.6 ± 0.6</td>
<td>15.1 ± 2.7 ± 1.5</td>
</tr>
</tbody>
</table>
Conclusion

- Worlds best measurement of $D_{(s)}$ absolute branching fractions – aim to achieve $\sim 4\%$ for $D_s$ decays with more data
- Worlds best $D_{(s)}$ decay constants provide test of Lattice QCD (and other models) and probe beyond-SM physics
- $\psi(2S)$ as well as $\chi_c$ decays provide rich opportunity to study charmonium spectroscopy, decay mechanisms, and light hadrons

More data on the way: taking data until April 2008
Stay tuned for more results from CLEO-c!
Extra slides
Constraint on new physics from $D_{(s)} \rightarrow \ell \nu$

- Relative decay rate to leptons can be modified by factor $r$ due to $H^+$
- In MSSM the extra factor is (Akeroyd, hep-ph/0308260)

$$r = \left[ 1 - m_{D_{q}}^{2} R^{2} \left( \frac{m_{q}}{m_{c}} \right)^{2} \right]^{2}$$

where $R = \tan \beta / m_{H}$

- Larger effect for $D_{s}$: $r \propto (m_{q}/m_{c})$
- Our results

$$\frac{\Gamma(D_{s}^{+} \rightarrow \tau^{+}\nu)}{\Gamma(D_{s}^{+} \rightarrow \mu^{+}\nu)} = 9.9 \pm 1.7 \pm 0.7$$  
  (SM = 9.72)

$$\frac{\Gamma(D^{+} \rightarrow \tau^{+}\nu)}{\Gamma(D^{+} \rightarrow \mu^{+}\nu)} < 4.77 \text{ (90\% cl)}$$  
  (SM = 2.65)

$r = \text{Ratio/SM} > 1$ (Higgs: $r < 1$)

Can set limit on $\tan \beta$ vs. $m_{H}$ plane but depends on theory – do not take seriously yet!
Dalitz plot formalism

- Log likelihood:
  \[ \mathcal{L} = -2 \sum_{n=1}^{N} \log PDF(x_n, y_n) \]

- PDF:
  \[ PDF(x, y) = \begin{cases} 
    \varepsilon(x, y) \\
    B(x, y) \\
    fN_S|\mathcal{M}(x, y)|^2\varepsilon(x, y) + (1-f)N_B B(x, y)
  \end{cases} \]

- Matrix element:
  \[ |M|^2 = \sum_R |A_R|^2 \Omega_R^2 \]
  non-interfering resonances

- Amplitude of each resonance contribution \( A_R \):
  - Breit-Wigner parametrization with mass-dependent width (for narrow resonances)
  - Complex pole for S-wave (\( \sigma, \kappa \)):
    \[ \frac{1}{m_R^2 - m^2} \]
  - Flatte parametrization for \( a_0(980) \):
    \[ \frac{1}{m_R^2 - m^2 - i(g_{\eta\pi}^2 \rho_{\eta\pi} + g_{KK}^2 \rho_{KK})} \]

- Angular distribution \( \Omega_R \):