CLEO HOT Topics

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FPCP, Taipei, May, 2008
Favored Methods at CLEO-c

- Two-body production $e^+e^- \rightarrow D\bar{D}$

- Double tags at 3770 MeV: fully reconstruct one $D^0$ or $D^+$, then can either fully reconstruct the other $D$ (absolute branching ratios, quantum correlations) or look for events with one missing particle (leptonic decays, semileptonic decays, $K_L$)

- Similarly, double tags at 4170 MeV: here look for a $D_S$ or a $D_S^*$

- Some measurements also done using single tags
Absolute $D_S$ Branching Ratios

Use ratio of Double tags/Single tags. To 1st order:

- $\#D_1 = 2N_{DD}\varepsilon_1 \mathcal{B}_1$
- $\#D_{11} = N_{DD}\varepsilon_1^2 \mathcal{B}_1^2$
- $\therefore \#D_{11}/\#D_1 = (1/2) \varepsilon_1 \mathcal{B}_1$
- $\mathcal{B}_1 = (2/\varepsilon_1) (\#D_{11}/\#D_1)$
- We use all combinations of these modes
D_S Absolute \( \mathcal{B} \) Results (300 pb\(^{-1}\))

<table>
<thead>
<tr>
<th>Mode</th>
<th>This Result ( \mathcal{B} ) (%)</th>
<th>PDG 2007 fit ( \mathcal{B} ) (%)</th>
<th>( \mathcal{B}/\mathcal{B}(K^-K^+\pi^+) )</th>
<th>( \mathcal{A}_{CP} ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K_S^0 K^+ )</td>
<td>1.49 ± 0.07 ± 0.05</td>
<td>2.2 ± 0.4</td>
<td>0.270 ± 0.009 ± 0.008</td>
<td>+4.9 ± 2.1 ± 0.9</td>
</tr>
<tr>
<td>( K^-K^+\pi^+ )</td>
<td>5.50 ± 0.23 ± 0.16</td>
<td>5.3 ± 0.8</td>
<td>1</td>
<td>+0.3 ± 1.1 ± 0.8</td>
</tr>
<tr>
<td>( K^-K^+\pi^+\pi^0 )</td>
<td>5.65 ± 0.29 ± 0.40</td>
<td>—</td>
<td>1.03 ± 0.05 ± 0.08</td>
<td>-5.9 ± 4.2 ± 1.2</td>
</tr>
<tr>
<td>( K_S^0 K^-\pi^+\pi^+ )</td>
<td>1.64 ± 0.10 ± 0.07</td>
<td>2.7 ± 0.7</td>
<td>0.298 ± 0.014 ± 0.011</td>
<td>-0.7 ± 3.6 ± 1.1</td>
</tr>
<tr>
<td>( \pi^+\pi^+\pi^- )</td>
<td>1.11 ± 0.07 ± 0.04</td>
<td>1.24 ± 0.20</td>
<td>0.202 ± 0.011 ± 0.009</td>
<td>+2.0 ± 4.6 ± 0.7</td>
</tr>
<tr>
<td>( \pi^+\eta )</td>
<td>1.58 ± 0.11 ± 0.18</td>
<td>2.16 ± 0.30</td>
<td>0.288 ± 0.018 ± 0.033</td>
<td>-8.2 ± 5.2 ± 0.8</td>
</tr>
<tr>
<td>( \pi^+\eta' )</td>
<td>3.77 ± 0.25 ± 0.30</td>
<td>4.8 ± 0.6</td>
<td>0.69 ± 0.04 ± 0.06</td>
<td>-5.5 ± 3.7 ± 1.2</td>
</tr>
<tr>
<td>( K^+\pi^+\pi^- )</td>
<td>0.69 ± 0.05 ± 0.03</td>
<td>0.67 ± 0.13</td>
<td>0.125 ± 0.009 ± 0.005</td>
<td>+11.2 ± 7.0 ± 0.9</td>
</tr>
</tbody>
</table>

\( \mathcal{B}(D_S^+\rightarrow\phi\pi^+) \) – Unfortunately not well defined due to interference of overlapping resonances. Value depends on both mass resolution & cut in \( K^+K^- \) mass

<table>
<thead>
<tr>
<th>( K^+K^- ) mass cut</th>
<th>( \mathcal{B}(D_S^+\rightarrow\phi\pi^+) ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>± 5 MeV</td>
<td>3.43±0.16±0.12</td>
</tr>
<tr>
<td>±10 MeV</td>
<td>4.04±0.20±0.10</td>
</tr>
<tr>
<td>±15 MeV</td>
<td>4.35±0.20±0.10</td>
</tr>
<tr>
<td>±20 MeV</td>
<td>4.55±0.22±0.12</td>
</tr>
</tbody>
</table>

background subtracted yield in \( K^+K^-\pi \) events
Input to D Mixing Measurements

- Rate of $D$ mixing parameterised by $x=2\Delta M/\Gamma$ & $y=\Delta \Gamma/\Gamma$.
- Time-dependent wrong-sign rate $D^0 \rightarrow K^-\pi^+$:
  - Sensitivity via interference between DCS and mixing amplitudes
    \[ A_{DCS}/A_{CF} = \langle K^-\pi^+|\bar{D}\rangle / \langle K^-\pi^+|D^0\rangle = -re^{-i\delta} \]
  - Where the strong phase causes a problem: $y'=y \cos \delta - x \sin \delta$
  - Direct comparison with $y$ measurements from $CP$-eigenstate lifetimes and time-dependent measurements of $D \rightarrow K_S\pi\pi$
    Dalitz plot are not possible without determination of $\delta$
- $\delta$ and other mixing parameters can be measured in quantum correlated $D\bar{D}$ decay at CLEO-c
  - See Asner talk later in the week & arXiv:0802.2268v1 [hep-ex]
Coherent vs. Incoherent Decay

- \( R_M = \frac{x^2+y^2}{2} \), \( R_{WS} = r^2 + ry' + R_M \)
- Double tag rates:

<table>
<thead>
<tr>
<th>DT</th>
<th>( K^-\pi^+ )</th>
<th>( e^- )</th>
<th>( CP^+ )</th>
<th>( CP^- )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K^-\pi^+ )</td>
<td>( R_M / R_{WS} )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( K^+\pi^- )</td>
<td>( 1 + 2R_{WS} - 4r\cos\delta ) (( r\cos\delta + y ))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( e^- )</td>
<td>( 1 - r ) (( y\cos\delta + x\sin\delta ))</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( CP^+ )</td>
<td>( 1 + \frac{(2r\cos\delta + y)}{(1 + R_{WS})} )</td>
<td>( 1 + y )</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>( CP^- )</td>
<td>( 1 - \frac{(2r\cos\delta + y)}{(1 + R_{WS})} )</td>
<td>( 1 - y )</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>ST</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

- Compare coherent/incoherent branching fractions, where the double tags supply the coherent rates
- Leads to \( \delta = (22^{+11+9}_{-12-11})^\circ \)

See Yabsley talk
Help In Measuring $\gamma$

- Recall ADS method

\[ \Gamma(B^- \rightarrow (K^+\pi^-)_D K^-) \propto r_B^2 + (r_D^{K\pi})^2 + 2r_B r_D^{K\pi} \cdot \cos(\delta_B + \delta_D^{K\pi} - \gamma) \]

- One key rate is

\[ \Gamma(B^- \rightarrow (K^+\pi^-\pi^-\pi^+)_D K^-) \propto r_B^2 + (r_D^{K3\pi})^2 + 2r_B r_D^{K3\pi} R_{K3\pi} \cdot \cos(\delta_B + \delta_D^{K3\pi} - \gamma) \]

- Can use $D^o \rightarrow K^-\pi^+\pi^+\pi^-$ instead of $K^-\pi^+$:

- If coherence factor is small can help measure $r_B$, since $r_B$ is the same in both cases.
Limits on $R_{K3\pi}$

- We find
- See Asner’s talk for details

Preliminary Results

(281 pb$^{-1}$)
Leptonic Decays: $D \rightarrow \ell^+ \nu$

Introduction: Pseudoscalar decay constants $c$ and $\bar{q}$ can annihilate, probability is proportional to wave function overlap.

Feynman diagram in Standard Model:

In general for all pseudoscalars:

$$\Gamma(P^+ \rightarrow \ell^+ \nu) = \frac{1}{8\pi} G_F^2 f_P^2 m_\ell^2 M_P \left(1 - \frac{m_\ell^2}{M_P^2}\right)^2 |V_{Qq}|^2$$

Calculate, or measure if $V_{Qq}$ is known, here take $V_{cd} = V_{us} = 0.2256$. 

FPCP May, 2008
New Unquenched Lattice Calc

- Follana et al HPQCD & UKQCD collaborations (PRL 100, 062002 (2008))
- New predictions of
  \( f_{D^+} = 207 \pm 4 \) MeV
  \( f_{D_s} = 241 \pm 3 \) MeV

- Older unquenched from FNAL+MILC +HPQCD are:
  \( f_{D^+} = 201 \pm 3 \pm 17 \) MeV
  \( f_{D_s} = 249 \pm 3 \pm 16 \) MeV
  (Aubin et al., PRL 95, 122002 (2005))
Situation Prior To FPCP 2008

- Experiment $f_{D_s}$: CLEO measures both $\mu^+\nu$ & $\tau^+\nu$, & Belle measures $\mu^+\nu$. Average is $3.3\sigma$ away, could be a weird fluctuation

- Dobrescu & Kronfeld (arXiv:0803.0512) argue that this can well be the effect of NP, either charged Higgs (their own model) or leptoquarks

- Here I will update both CLEO measurements (Details in dedicated talk)
Basic Technique for $D^+ \rightarrow \mu^+ \nu$

- Fully reconstruct a $D^-$, and count total # of tags
- Seek events with only one additional oppositely charged track within $|\cos \theta| < 0.9$ & no additional photons > 250 MeV (to veto $D^+ \rightarrow \pi^+ \pi^0$)
- Charged track must deposit only minimum energy (from ionization) in calorimeter < 300 MeV
- Compute $MM^2$. If close to zero then almost certainly we have a $\mu^+ \nu$ decay.

$$MM^2 = (E_{D^+} - E_{\ell^+})^2 - (\vec{p}_{D^+} - \vec{p}_{\ell^+})^2$$

We know $E_{D^+} = E_{\text{beam}}, \ p_{D^+} = - p_{D^-}$
Tags

- Now use 818 pb\(^{-1}\) of data on \(\psi(3770)\)
- Total of 460,000
- Background 89,400
The MM$^2$ Distribution

- For $E < 300$ MeV in CsI

![Graph showing $K^0\pi^+$ peak and $\mu^+\nu$ peak with $\tau^+\nu, \tau^+\rightarrow\pi^+\nu$ region marked]
Fit MM² to sum of signal & bkgrd

- $\tau^+\nu/\mu^+\nu$ is **fixed** to SM ratio
  - $149.7\pm12.0$ $\mu\nu$
  - $28.5$ $\tau\nu$

- $\tau^+\nu/\mu^+\nu$ is allowed to **float**
  - $153.9\pm13.5$ $\mu\nu$
  - $13.5\pm15.3$ $\tau\nu$
Branching Fractions & $f_{D^+}$

- **Fix $\tau\nu/\mu\nu$**
  - $\mathcal{B}(D^+\rightarrow\mu^+\nu) = (3.86\pm0.32\pm0.09) \times 10^{-4}$
  - $f_{D^+} = (206.7\pm8.5\pm2.5) \text{ MeV}$
  - This is best number in context of SM

- **Float $\tau\nu/\mu\nu$**
  - $\mathcal{B}(D^+\rightarrow\mu^+\nu) = (3.96\pm0.35\pm0.10) \times 10^{-4}$
  - $f_{D^+} = (208.5\pm9.3\pm2.5) \text{ MeV}$
  - This is best number for use with Non-SM models
Improved Measurement of $f_{Ds}$

- CLEO has two methods of measuring $f_{Ds}$
  - Measure $\mu^+\nu$ & $\tau^+\nu$, $\tau^+ \rightarrow \pi^+\nu$ using similar MM$^2$ technique used for $D^+$. Update result using new analysis & 30% more data (total of $\sim 400$ pb$^{-1}$)
  - Measure $\tau^+ \rightarrow e^+\nu\nu$ by using missing energy. This result has not been updated (300 pb$^{-1}$)
Use $e^+e^- \rightarrow D_S D_{S}^*$ at 4170 MeV

- Reconstruct $D_S^-$, similar invariant mass distributions as for absolute $\mathcal{B}$ analysis
- Find the $\gamma$ from the $D_{S}^*$ & compute $MM^2$ from $D_S^-$ & $\gamma$
  \[
  MM^*^2 = (E_{CM} - E_{D} - E_{\gamma})^2 - (\vec{p}_D - \vec{p}_{\gamma})^2
  \]
- Select combinations consistent with a missing $D_S^+$ & count the number
- Find $MM^2$ from candidate muons in the tag sample, where
  \[
  MM^2 = (E_{CM} - E_{D} - E_{\gamma} - E_{\mu})^2 - (\vec{p}_D - \vec{p}_{\gamma} - \vec{p}_{\mu})^2
  \]
MM*² Distributions From D_s⁻ + γ

- K⁺K⁻π⁻
- KSK⁻
- ηπ⁻
- η'π⁻
- η' → π⁻π⁺η
- K⁺K⁻π⁻π₀
- π⁻π⁻π⁺
- K*₀K*
- η'ρ
- η' → ργ

FPCP May, 2008
Fit to signal & background

Fit to $MM^2$

- Background
- $D_S$ sidebands
- Extra $\gamma$ background

Events / $(0.02 \text{ GeV}^2)$ vs. $MM^2(\text{GeV}^2)$

- $\mu^+\nu$
- $\tau^+$
- $\gamma$
Conclusions on Decay Constants

- We are in close agreement with the Follana et al calculation for \( f_{D^+} \). This gives credence to their methods.
- The disagreement with \( f_{D_s} \) is enhanced.

![Graph showing decay constants with values and error bars]
Consequences

Pick your favorite of the two:

- If theoretical predictions of $f_{D_s}/f_{D^+}$ do not agree with the data, why should we believe $f_{B_s}/f_B$ from theory? What does this do to the CKM fits?

- If there is New Physics affecting leptonic $D_S$ decays, how does it affect $B_S$ mixing and other $B_S$ decays? (See A. Kundu & S. Nandi, “R-parity violating supersymmetry, $B_S$ mixing, & $D_S^+ \to \ell^+\nu$” [arXiv:0803.1898])
IF There is a Shift ..

- If increases the radius of the $\Delta m_d / \Delta m_s$ constraint increases
- Red arrow indicates a shift of $\sim 10\%$ in $f_{B_s} / f_B$
Discovery of $D_s^+ \rightarrow p\bar{n}$

- Use same technique as for $\mu^+\nu$, but plot MM from an identified proton
- No background
- First example of a charm meson decaying into baryons

$B(D_s^+ \rightarrow p\bar{n}) = \left(1.30 \pm 0.36^{+0.12}_{-0.16}\right) \times 10^{-3}$

- Consequences for understanding W annihilation dynamics

see Chen, Cheng & Hsiao  arXiv:0803.2910v3 [hep-ph]
Higgs Search from Y(1S) Decays

- Some NMSSM models (Dermisek, Gunion, McElrath: PRD D76, 051105(2007)) avoid the LEP limit on the Higgs mass by postulating a new non-SM-like Higgs boson $a_1$ (a pseudoscalar) with $m_a < 2m_b$, where $H \rightarrow a_1 a_1$

- A good place to search for the $a_1$ is in radiative Upsilon decays, $\Upsilon \rightarrow \gamma a_1$.

- The $a_1$ would decay predominantly into heaviest down-type pair of fermions available.

- HyperCP observed 3 $\Sigma^+ \rightarrow \rho \mu^+ \mu^-$ events, mass $214.3 \pm 0.5$ MeV. He, Tandean, Valencia PRL 98, 081802 (2007) interpret this as evidence for $a_1$ with 214.3 MeV mass, since below $\tau^+ \tau^-$ threshold $a_1 \rightarrow \mu^+ \mu^-$ would be large.
CLEO Search

- We use 21.5 M Y(1S) decays collected with the CLEO III detector
- For the $a_1 \rightarrow \tau^+\tau^-$ search we examine the photon energy spectrum in events with missing energy & one identified $\mu^\pm$ or $e^\pm$ (allegedly from $\tau \rightarrow e\nu\nu$ or $\tau \rightarrow \mu\nu\nu$)
- For the $a_1 \rightarrow \mu^+\mu^-$ search we examine the photon energy spectrum in events with no missing energy & two identified $\mu^\pm$
- No narrow peaks are observed, except for $Y(1S) \rightarrow \gamma J/\psi \rightarrow \gamma \mu^+\mu^-$
Constraints on NMSSM from $\gamma\tau^+\tau^-$

From Dermisek, Gunion, McElrath: hep-ph/0612031

Many models with $2m_\tau < m_a < 7.5$ GeV (represented by red points) ruled out by our results.

Colors represent different mass ranges
Constraints on NMSSM from $\gamma \mu^+\mu^-$

- $\varepsilon(Y(1S)\rightarrow\gamma\mu^+\mu^-)$

Eliminates all of NMSSM models for $m_{a_1} < 2m_\tau$ (blue points)

*Preliminary*

Colors represent different mass ranges
Summary of Higgs Search

- We have obtained meaningful limits on $\mathcal{B}(Y(1S) \rightarrow \gamma a_1)^* \mathcal{B}(a_1 \rightarrow \tau^+ \tau^-)$ & $\mathcal{B}(Y(1S) \rightarrow \gamma a_1)^* \mathcal{B}(a_1 \rightarrow \mu^+ \mu^-)$

- Using $\gamma \tau^+ \tau^-$ we eliminate a large portion of previously unconstrained parameter space in the NMSSM model

- Using $\gamma \mu^+ \mu^-$ we eliminate the entire parameter space in NMSSM model, for $m_{a_1} < 2m_\tau$ except when the $a_1$ is pure singlet

- There is no evidence for a CP-odd Higgs state decaying to $\mu^+ \mu^-$ with a mass of 214.3 MeV; our limit is much below the NMSSM expectations for $a_1$ at 214 MeV prompted the by HyperCP $\Sigma^+ \rightarrow p \mu^+ \mu^-$ event candidates
Hot Topics submitted to ICHEP

Analysis of the $D^+ \rightarrow K^+K^−\pi^+$ Dalitz plot
Analysis of the $D^+_s \rightarrow K^+K^−\pi^+$ Dalitz plot
Rare radiative $D$ meson decays

Improving the precision of $\gamma/\phi_3$ via CLEO-c Dalitz plot analysis

Determination of the strong phase in $D^0 \rightarrow K^+\pi^−$ using quantum-correlated measurements

Hadronic decays of the $D$ and $D_s$ mesons
Improved measurement of the pseudoscalar decay constant $f_{D^+_s}$
Improved measurement of the pseudoscalar decay constant $f_{D^+}$

Exclusive semileptonic decays of the $D_s$ meson

Exclusive semileptonic decays of the $D$ meson

$\Upsilon$ transitions and decays
Radiative and electromagnetic decays of charmonia
Spectroscopy in charmonia decays
All Invited

SYMPOSIUM
CELEBRATING
CLEO & CESR

Friday, May 30, 2008
Reception, Clark Hall

Saturday, May 31, 2008
Symposium, Cornell University
Ithaca, New York, USA

Invited Talks, Clark Hall
Dinner, Statler Hotel

For information and to register, visit: www.lepp.cornell.edu/Events/CLEOCESRSymp/

MILESTONES

CESR
1975 CESR proposal
1977 RF funding approved
1979 Protocalorimeter beam test + collimators
1981 Main factory housing of interaction region
1983 Multiple-bend in proton beam
1986 Luminosity greater than 30 fb^-1
1994 Crossing angle and chicane trays
1999 Superconducting RF cavities
2003-04 CESR-capable rings

CLEO
1975 "South Area Experiment" group arrive (CLIO)
1976 Fast gas collected
1978 Beam discovered
1985 New detector enclosure installed
1986 LHe detector with CsI calorimeter installed
1990 + - - a meson discovered
1995 + -- a strange meson discovered
1996 CLEO IV with Si microstrip detector installed
1999 LHCb in CLIC installed
2000 LHCb data collection started
2004 LHCb data taken
2007 "everyday" run of CLIC announced
2007 CLIC paper published

FPCP May, 2008
The End

FPCP, Taipei, May, 2008
$e^+e^- \rightarrow D_s D_s^*$
$D_S^-$ Tags: Invariant Mass

$K^+K^-$

$K_SK^-$

$\eta\pi^-$

$\eta'^{\pi^-}$

$\eta^{\gamma}$

$\eta'^{\rho^-}$

$\eta'^{\pi^-}$

$\eta'^{\rho^-}$
MM$^2$ data for D$_S$

- Total of 30,848±695 tags
- 99% of $\mu^+\nu$ in $E < 300$ MeV
- 55%/45% split of $\tau^+\nu$, $\tau^+\rightarrow\pi^+\nu$ in two cases
- Small e$^-$ background