Light Meson Spectroscopy at CLEO-c

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(for the CLEO Collaboration)

April 9, 2008
International Workshop on e^+e^- Collisions from Φ to Ψ
The CLEO-c Physics Program

• Three major data sets:
  • 818 pb$^{-1}$ sample taken at $\psi(3770)$ which will yield over 5 million DD events
    - studies of quantum correlated decays, mixing, precision flavor physics (J. Libby - Monday)
    - light meson spectroscopy in multi-body D decays
  • $\sim$600 pb$^{-1}$ taken at $E_{CM} = 4170$ MeV where $D_s$ production is enhanced
    - $D_s$ leptonic and semileptonic form factors
  • 58 pb$^{-1}$ at $\psi' \rightarrow 27$ million $\psi'$ decays, clean source of “tagged” $J/\psi$ and $\chi_c$
    - QCD in the charmonium system \textit{tomorrow!}
    - production and properties of light mesons in decay of charmonia
  • Scan of open charm cross sections from 3.97 - 4.26 GeV (J. Libby - yesterday)
The Charmonium System: An Outline

- Studies of light meson properties in transitions and decay of charmonia

- Results:
  - $\eta$ mass and branching fraction measurements in $\psi' \to \eta \ J/\psi$
  - spectroscopy in decays of the $\chi_c$
  - light meson interactions on the $D^+ \to K^- \pi^+ \pi^+$ Dalitz plot
Use the transition $\psi' \to \eta J/\psi$, with $J/\psi \to \ell^+\ell^-$, to study the properties of the $\eta$

Kinematic fitting of both $J/\psi$ and $\psi'$ to known masses improves $\eta$ mass resolution (test technique on $\pi^0$):

$$M_{\eta} = 547.785 \pm 0.017 \pm 0.057 \text{ MeV}$$

Compare w/KLOE Update

**JHEP 0712, 073 (2007):**

$M_{\eta} = 547.873 \pm 0.007 \pm 0.029 \text{ MeV}$

Good agreement!
Apply similar technique to simultaneously measure all allowed branching fractions of $\eta$

Construct absolute branching fractions by measuring all possible branching fraction ratios

Assume measured modes comprise all modes (limit on “other” < 0.2%)

Systematics are well under control since all measurements are made with the same experiment
Hadronic $\chi_{cJ}$ Decays

- Decays of $\chi_c$ proceed by annihilation into light quarks -- patterns of decays may provide insight on light meson and glueball structure.

- $\chi_c$ produced in electromagnetic transitions from the $\Psi'$

- BF $\sim$8-10% provides high statistics $\chi_c$ sample

- Search for various hadronic multi-body decay modes of $\chi_c$

Analysis relies on identification of all decay products and kinematic fit to initial $\Psi'$ four-momentum.
It is interesting that $B(J/\psi \rightarrow \omega f_0(1710))$ is greater than $B(J/\psi \rightarrow \phi f_0(1710))$ given $f_0(1710)$ is thought to be largely strange.

- Suggestive of large OZI violating effects in $J/\psi$ decay? .....glueball mixing? (F. Close and Q. Zhao, PRD 71, 094022)

- Look for similar effects in $\chi_c$ decays to the pseudoscalar isoscalars
  - connected to $\eta$-glueball mixing

- Use the factorization scheme proposed by Q. Zhao (PRD 72, 074001; PLB 659, 221)

$r =$ relative strength between singly-OZI and doubly-OZI suppressed transition amplitudes
\( \chi_{cJ} \rightarrow \eta(\prime)\eta(\prime) \)

- Analysis utilizes the large 25M \( \psi' \) sample
- Supersedes previous CLEO analysis on 3M \( \psi' \) (PRD 75, 071101(R)(2007))

<table>
<thead>
<tr>
<th>B.F. ( \times 10^{-3} )</th>
<th>( \chi_{c0} )</th>
<th>( \chi_{c2} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \eta \eta )</td>
<td>3.18±0.13±0.18±0.16</td>
<td>0.51±0.05±0.03±0.03</td>
</tr>
<tr>
<td>( \eta'\eta' )</td>
<td>&lt;0.25 (90% CL)</td>
<td>&lt;0.05 (90% CL)</td>
</tr>
<tr>
<td>( \eta\eta' )</td>
<td>2.12±0.13±0.11±0.11</td>
<td>0.06±0.03±0.004±0.004 &lt; 0.10 (90%CL)</td>
</tr>
</tbody>
</table>

Errors: (stat.) ± (syst.) ± (B(\( \psi' \rightarrow \gamma \chi_{cJ} \)))

CLEO Preliminary
Predicted dependence of BR on r (DOZI/SOZI) (from Q. Zhao (PRD 72, 074001))

\[ \chi_{cJ} \rightarrow \eta^(')\eta^(') \]

Data suggest small if any contribution for DOZI decays in $0^+ \rightarrow h^+$ channel.

Similar analysis for scalars ($0^{++}$) can be carried out.
\( \chi_{c1} \rightarrow h^+ h^- h^0 \)

- Three body decays of \( \chi_c \) states provide an opportunity to explore light quark mesons through Dalitz plot structure
- Kinematic fit provides nearly background free sample
- Heavy \( \chi_c \) provides large phase space for light meson production
- Low multiplicity decay modes are relatively easy to reconstruct and analyze
- Results use pilot sample of 3M \( \Psi' \)
  
  PRD 75, 032002 (2007)
**CLEO now has an order of magnitude more statistics:**
a couple thousand events on the Dalitz plot

The rudimentary Dalitz fit neglects $\chi_{c1}$ polarization and interference. See PRD 75, 032002 (2007) for fit fractions.
\[ D^+ \rightarrow K^- \pi^+ \pi^+ \]

- Use 572 pb\(^{-1}\) \(\psi(3770)\) decays to open charm as a clean source of D decays
- Select candidates using energy and momentum conservation

\[ \Delta E = E_D - E_{\text{beam}}, \]
\[ m_{\text{BC}} = \sqrt{E_{\text{beam}}^2 - P_D^2}, \]

- Very clean sample: 140793 signal candidates with only 1.1% background
- Study light hadron substructure
- Perform a fit to the Dalitz plot, including contributions from $K$, $K^*(892)$, $K_0^*(1430)$, $K_2^*(1430)$, and $K^*(1680)$
- Asymmetry in $K^*(892)$ peak is an indicator of interference with a scalar $K\pi$ component
- Additional $I=2$ $\pi^+\pi^+$ $S$ wave is needed to achieve an adequate fit to the data
- Isobar model description not sufficient for high precision analysis

**D^+ \rightarrow K^- \pi^+ \pi^+**

- Fit for amplitude and phase in bins of K\pi or \pi\pi mass (quasi-model-independent PWA) [E791: PRD 73, 32004]
- K\pi S wave does not look like a Breit-Wigner resonance
- I=2 \pi\pi S wave consistent with \pi\pi scattering data

Example: K^- \pi^+ D wave

K^- \pi^+ S wave

I= 2 \pi^+ \pi^+ S wave

Summary

- Decays of charmonia and charm mesons provide nice opportunity to study light meson properties
- With large, clean open charm and $\psi'$ samples CLEO-c continues to make excellent contributions in this area:
  - precision measurements of $\eta$ mass and branching fractions
  - formation of light hadrons in two-body $\chi_c$ decays and implications on meson structure
  - study of properties of light hadrons with the substructure of multibody $\chi_c$ and D decays
- Data taking has now been completed -- expect many more results this summer!
\[ D^+ \rightarrow K^- \pi^+ \pi^+ \]

Breit-Wigner, Flatte, complex pole, \( l=2 \) \( \pi^+ \pi^+ \) wave, binned

\[
\mathcal{W}_R(m) = \frac{1}{m_R^2 - m^2 - i m_R \Gamma_{R,\text{total}}(m)}
\]

\[
\Gamma_{R,\text{total}}(m) = \Gamma_R \frac{m_R}{m} \left( \frac{\rho}{\rho_R} \right)^{2L+1} \left[ \frac{\mathcal{F}_R^L(\rho \cdot \tau_R)}{\mathcal{F}_R^L(\rho_R \cdot \tau_R)} \right]^2
\]

\[
\mathcal{W}_R(m) = \frac{1}{m_R^2 - m^2 - i \sum_{ab} g^2_{Rab} \rho_{ab}(m)}
\]

\[
\mathcal{W}_R(m) = \frac{1}{s_R - m^2} \quad s_R = (0.71 - i0.31)^2 \text{ GeV}^2
\]

\[
\mathcal{W}_{L=0}^{L=2}(m) = \frac{\eta_0^2(m) e^{i \delta_0^2(m)} - 1}{2i}
\]

\[
W_L \text{ binned}(s) = a_{Lk}(s) \cdot e^{i \phi_{Lk}(s)}
\]

\( \eta, \delta \) parametrized vs \( m \)