Beyond SM Physics at a CLEO Charm Factory
(some food for thought)
Mats Selen, UIUC, May/5/2001

- Data Assumptions
- Tagging
- Rare decays
- D mixing
- CP violation
- Off The Wall
Data Assumptions

• Assume we will accumulate 3 fb\(^{-1}\) on the \(\psi'(3770)\)
  – 10 nb signal, 12 nb “other hadronic”:
  – About 3x10\(^7\) \(D\bar{D}\) pairs

• Assume BaBar & Belle will (each) have 400 fb\(^{-1}\) on the \(\Upsilon(4S)\)
  – 1.3 nb signal, 3 nb “other hadronic”
  – About 5x10\(^8\) \(c\bar{c}\) pairs each

• Our competition will have \(~17\) times more charm
  on \(~33\) times more “other hadronic” background.
Big Advantage: Tagging:

Two important benefits:
- Flavor ID
- Unambiguously Reconstruction

- Suppose efficiency x BR (all tags) = 10% (more on this..)
- Will have ~ 10^6 each tagged D^0 and D^+ per 1 fb^{-1}
- Limits of order 10^{-6} possible from 3 fb^{-1} data (still pretty good)
Example Study: $D^0 \rightarrow \pi^0 \ e^+e^-$
($\Delta C=1$ Weak Neutral Current)

Tag using:
$D^0 \rightarrow K^-\pi^+$ ($B = 3.83\%$)  
$D^0 \rightarrow K^-\pi^+\pi^0$ ($B = 13.9\%$)

In 32290 generic $D^0$ decays:
- 1098 $D^0 \rightarrow K^-\pi^+$ tags ($\varepsilon B=3.4\%$)
- 1543 $D^0 \rightarrow K^-\pi^+\pi^0$ tags ($\varepsilon B=4.8\%$)

With just these two modes, $\varepsilon B_{tag}=8.2\%$

Working Group: What is the tradeoff: efficiency vs cleanliness
Tagged events
\[ \epsilon_{\pi^e e^e} \times \epsilon_{\text{Btag}} = 1.5\% \]

\( \sim 500 \text{ evt} \)

...if we don’t properly exclude tagged tracks

Ability to get rid of this stuff is a key advantage!
Suppose $\varepsilon_{\pi e e} \cdot \varepsilon_{B_{\text{tag}}} = 1.5\%$

Suppose we have 3 fb$^{-1}$ ($\sim 1.5 \times 10^7 D^0\bar{D}^0$ pairs)

Suppose we see 0 events

90% CL upper limit is $\sim 5 \times 10^{-6}$

Most modes studied were in the $10^{-6} \rightarrow 10^{-5}$ range

About a factor of 100 improvement over PDG in most cases.

It's hard to imagine BaBar/Belle would not be in the same ballpark, although based on simple scaling I think we have the edge in clean modes where they are background limited. See Excel Table

See Bruce Yabsley's talk in beyond SM working group
Simple spreadsheet analysis tool available for working group.

For example…

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Some interesting examples:

1) $B(D^0 \rightarrow \gamma \gamma)$ - SM small: $\sim 10^{-8}$ (Singer et. al. hep-ph/0104236)
   - good hunting for physics beyond SM.
   - no present limit, CLEO-c sensitivity $\sim 10^{-6}$

2) $\Gamma(D^0 \rightarrow \rho \gamma) / \Gamma(D^0 \rightarrow \omega \gamma)$ (Fajfer et. al. hep-ph/0006054)
   - Individual BR’s small: $\sim 10^{-6}$
   - Long distance effects cancel in ratio.
   - Ratio should be $\sim 1$ (30% deviation means new physics)

Presently:
90% CL Upper Limits < $2.4 \times 10^{-4}$
For both modes

See Will Johns’ talk in beyond SM working group
Mixing Phenomenology:

In hadronic decays:

$$y = \frac{\Delta \Gamma}{2 \Gamma} \text{ (real)}$$

$$x = \frac{\Delta M}{\Gamma} \text{ (virtual)}$$

$$\delta = \delta_R - \delta_W$$

$$r = \frac{\bar{A}}{A}$$

$$\langle K^{-}\pi^+ | D^0 \rangle \equiv Ae^{i\delta_R}$$

$$\langle K^{-}\pi^+ | \bar{D}^0 \rangle \equiv \bar{A}e^{i\delta_W}$$

(important to measure)
D⁰-¯¯¯¯D⁰ Mixing: At the Y(4S)

Pro

• Lots of data
• Time evolution handle

Con

• Ultimately limited by Backgrounds & Systematics

Unmixed Decays $<t>=1$

Mixed Decays $<t>=3$

CLEO K₃π analysis

CLEO K*ν analysis
Experimental Situation (May/2001)

y Values from Lifetime Differences

- CLEO (2001) prelim
- Belle (2000) prelim *
- FOCUS (2000)
- E791 (1999)

CLEO II.V $D^0 \rightarrow K^+\pi^-$
- $D^0 \rightarrow K^+K^-$
- $E791 \rightarrow K^+1\nu$

$\delta_{\text{strong}}=0$

95% Allowed (Bayesian)
**D⁰-ᵐD⁰ Mixing: At the ψ”(3770)**

**Con**

- No Time evolution handle: D⁰’s produced ~at rest
- Can’t measure ΔΓ directly using lifetime differences.

**Pro**

- Tagging!
  - Flavor known
  - All tracks accounted for
- Quantum Correlations
  - opens up new avenues of search:
• The $D^0$ and $\bar{D}^0$ are produced coherently in a $J^{PC} = 1^{--}$ state.

$$\psi_{INITIAL} = \frac{1}{\sqrt{2}} \left[ D^0(\hat{p})\bar{D}^0(-\hat{p}) - \bar{D}^0(\hat{p})D^0(-\hat{p}) \right]$$

• Time integrated decay rate to final state $f_1, f_2$:

$$\Gamma(f_1, f_2) = \frac{1}{2} |A|^2 \left[ \frac{1}{1-y^2} + \frac{1}{1+x^2} \right] + \frac{1}{2} |B|^2 \left[ \frac{1}{1-y^2} - \frac{1}{1+x^2} \right]$$

Looks slightly different for $C^+$ initial states like $DD\gamma$

$$A = \langle f_1 | D^0 \rangle \langle f_2 | \bar{D}^0 \rangle - \langle f_1 | \bar{D}^0 \rangle \langle f_2 | D^0 \rangle$$

(assumes CP conserved)

$$B = \langle f_1 | D^0 \rangle \langle f_2 | D^0 \rangle - \langle f_1 | \bar{D}^0 \rangle \langle f_2 | \bar{D}^0 \rangle$$

See hep-ph/0103110
Gronau, Grossman & Rosner
(and also working group tomorrow)
Interesting Case 1:

Ratio of Rates:

\[
\frac{\Gamma(K^- \pi^+, K^- \pi^+)}{\Gamma(K^- \pi^+, K^+ \pi^-)} = \frac{1}{2} (x^2 + y^2) + \text{smaller terms}
\]

Useful for probing $x$ & $y$
Interesting Case 2:

Asymmetry =

\[ \frac{\text{CP+ eigenstate}}{\text{CP- eigenstate}} \]

\[ = 2r \cos \delta \]

Useful for probing \( r \) & \( \delta \)

There are several other interesting cases to study:
See Jon Rosner’s & Alexey Petrof’s talks in beyond SM working group
**Another Example:** $D^0 \rightarrow \bar{K}^0 \pi^+ \pi^-$ Dalitz Plot Analysis to extract mixing parameters:

- **CF:** $D^0 \rightarrow K^{-} \pi^{+}$
- **Mix or DCS:** $D^0 \rightarrow K^{*-} \pi^{-}$

...along with other good stuff: other $K^{*}$'s, $K_2$, $\rho$, $\omega$, $f_0$, $f_2$...
In CLEO II.V:
Sensitivity to x & y will be about 3%
See “wrong sign” decays at 5\(\sigma\) level.

See David Asner’s talk in beyond SM working group
Yet another Example: $D^0 \rightarrow \pi^+ \pi^- \pi^0$ Dalitz Plot Analysis:

Also accessible from the $\bar{D}^0 \rightarrow K^0 \pi^0$ Interference!
CLEO-II.V $D^0 \rightarrow \pi^+\pi^-\pi^0$ Dalitz Plot Analysis (preliminary):

At CLEO-c we will have 5-10x more events with no background
Direct CP violation:

Need two paths from initial $D$ to final state $f$.

Compare $D \rightarrow f$ to $\bar{D} \rightarrow \bar{f}$

$A_f = A_1 e^{i\delta_1} + A_2 e^{i\delta_2}$

$\bar{A}_f = A_1^* e^{i\delta_1} + A_2^* e^{i\delta_2}$
Direct CP violation:

Find: \[ A_{CP} = \frac{|A_f|^2 - |A_{\bar{f}}|^2}{|A_f|^2 + |A_{\bar{f}}|^2} \Rightarrow \frac{2 \text{Im}(A_1^*A_2) \sin(\delta_1 - \delta_2)}{|A_1|^2 + |A_2|^2 + 2 \text{Re}(A_1^*A_2) \cos(\delta_1 - \delta_2)} \]

**Good News:** We know large strong phase differences \((\delta_1 - \delta_2)\) are not uncommon in charm decays! This is an important ingredient.

**Good/Bad News:** Expect small weak phase differences in Standard Model. SM \(A_{CP}\) may be as big as \(10^{-3}\) for some decay modes

**Definitely a hunting ground for new physics.**
At the $\psi''(3770)$

$e^+e^- \rightarrow \psi'' \rightarrow D^0\bar{D}^0$

$J^{PC} = 1^{--}$

i.e. CP+ 

Suppose both $D^0$'s decay to CP eigestates $f_1$ and $f_2$:

These can **NOT** have the **same CP** :

$CP(f_1,f_2) = CP(f_1) \cdot CP(f_2) \cdot (-1)^l = CP-$

Observing this is evidence of CP
CP violation in Dalitz Plots:

Example Search: $D^0 \rightarrow K^- \pi^+ \pi^0$
Fit $D^0$ and $\bar{D}^0$ Dalitz Plots separately and look for asymmetries:

$$A_{CP} = \int \frac{|M_{D^0}|^2 - |M_{\bar{D}^0}|^2}{|M_{D^0}|^2 + |M_{\bar{D}^0}|^2} dD\bar{D}$$

Find $A_{CP} = 0.031 \pm 0.086$

Q: Are structural differences that integrate to zero interesting?

Better sensitivity to new physics expected in CS modes. Some are under investigation: $D^0 \rightarrow K^-K^+\pi^0$ and $D^0 \rightarrow \pi^-\pi^+\pi^0$

This will be easier to do at a charm factory than at $Y(4S)$ due to backgrounds.

See Daniele Pedrini’s talk in beyond SM working group.
General Observation

High statistics background free Dalitz Plot analyses will be a great place to look for interesting physics at CLEO-c

Not only “Beyond SM”, also QCD etc..
If there are $n$ large extra dimensions the decay $J/\psi \rightarrow \gamma + (h,\phi)$ may be sensitive to the compactification scale $M_S$:

The size $R$ of the extra dimension is given by $R^n \sim M_P^2 M_S^{-(n+2)}$ where $M_P$ is the 4-dimensional Planck scale.

Look for gravitational or dilatonic (undetected) graviton or dilaton (undetected)
If \( \text{BR}(J/\psi \rightarrow \gamma + (h, \phi)) < 10^{-5} \) we can set these lower bounds on \( M_S \) (as a function of \( n \)).

Predicted photon spectrum
There is lots of interesting physics “Beyond the Standard Model” that will be explored with CLEO-c.

Find out more at tomorrow's working group:

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**PROVISIONAL PROGRAM:**

**SUBGROUP ON CP VIOLATION IN CHARM DECAYS, RARE DECAYS, AND MIXING**

Sunday, May 6, 2001

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<tr>
<th>Session</th>
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<tbody>
<tr>
<td>Introduction</td>
<td>1:30 - 1:50</td>
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<tr>
<td>Mixing: Some tests that we can perform (Rosner)</td>
<td>1:50 - 2:10</td>
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<td>Mixing: What do we expect now? (x/y) (Petrov)</td>
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<td>Mixing: experimental perspective (David Asner)</td>
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<td>Discussion of mixing goals</td>
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<td>Break</td>
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<td>Rare decays: (Will Johns)</td>
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<td>CP Violation: (Daniele Pedrini)</td>
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<td>The competition (b-factories): (Bruce Yabsley)</td>
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<td>Discussion of goals in CP violation and rare decays</td>
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