NEW RESULTS IN D-MIXING

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Outline

- Parameters and Observables
- Current Status
- $y_{CP}$ from LHC-b
- Preliminary $y_{CP}$ from Belle, full data sample
- Preliminary $y_{CP}$ from BaBar, full data sample
- Conclusion
Parameters and Observables

- Define the mass eigenstates and phase conventions:

\[ |D_1\rangle = p|D^0\rangle + q|\bar{D}^0\rangle \]
\[ |D_2\rangle = p|D^0\rangle - q|\bar{D}^0\rangle \]
\[ |q|^2 + |p|^2 = 1 \]

\[ CP|D^0\rangle = -|\bar{D}^0\rangle \]
\[ CP|\bar{D}^0\rangle = -|D^0\rangle \]

- Mixing and CP violation (CPV) parameters:

\[ x = \frac{m_2 - m_1}{\Gamma} \]
\[ y = \frac{\Gamma_2 - \Gamma_1}{2\Gamma} \]
\[ \Gamma = \frac{\Gamma_1 + \Gamma_2}{2} \]

\[ \text{arg} \left( \frac{q}{p} \right) = \varphi \]

*note that \( \frac{q A_f}{p A_f} \) is the physical quantity and \( \varphi \) represents the weak phase from the mixing amplitude*
Parameters and Observables

Let's consider a generic final state $f$:

$$\langle f|H|D^0 \rangle = A_f \quad \langle f|H|\overline{D}^0 \rangle = \overline{A}_f$$

$$r(t) \propto \left| \langle f|H|D^0(t) \rangle \right|^2 = e^{-\Gamma t} \left\{ \left( |A_f|^2 + \left| \frac{q}{p} \right|^2 |\overline{A}_f|^2 \right) \cosh(\Gamma yt) - 2 \Re \left( \frac{q}{p} A_f^* \overline{A}_f \right) \sinh(\Gamma yt) \\
+ \left( |A_f|^2 - \left| \frac{q}{p} \right|^2 |\overline{A}_f|^2 \right) \cos(\Gamma xt) + 2 \Im \left( \frac{q}{p} A_f^* \overline{A}_f \right) \sin(\Gamma xt) \right\}$$

$$\bar{r}(t) \propto \left| \langle f|H|\overline{D}^0(t) \rangle \right|^2 = e^{-\Gamma t} \left\{ \left( |\overline{A}_f|^2 + \left| \frac{p}{q} \right|^2 |A_f|^2 \right) \cosh(\Gamma yt) - 2 \Re \left( \frac{p}{q} A_f A_f^* \right) \sinh(\Gamma yt) \\
+ \left( |\overline{A}_f|^2 - \left| \frac{p}{q} \right|^2 |A_f|^2 \right) \cos(\Gamma xt) + 2 \Im \left( \frac{p}{q} A_f A_f^* \right) \sin(\Gamma xt) \right\}$$

$$2y_{CP} = \left( |q/p| + |p/q| \right) y \cos \phi - \left( |q/p| - |p/q| \right) x \sin \phi$$
Current Status

- Mixing, even allowing for CP-violation, is firmly established.
No hint of new physics as $x \approx y$
**Measuring $y_{CP}$**

Assuming $|x| \ll 1, |y| \ll 1$ we have:

\[
\begin{align*}
    r(t) & \propto \exp(-t/\tau_{hh}^+) \\
    \bar{r}(t) & \propto \exp(-t/\bar{\tau}_{hh}^+)
\end{align*}
\]

*measured quantities*

We then extract the mixing parameter:

\[
y_{CP} = \frac{\tau_{K\pi}}{2} \left( \frac{1}{\tau_{hh}^+} + \frac{1}{\bar{\tau}_{hh}^+} \right) - 1
\]

\[
y_{CP} = \frac{\Gamma^+ + \Gamma^-}{2\Gamma_D} - 1
\]

\[
\tau_{hh}^+ = \tau(D^0 \rightarrow h^+ h^-) = \frac{1}{\Gamma^+}
\]

\[
\bar{\tau}_{hh}^+ = \tau(\bar{D}^0 \rightarrow h^+ h^-) = \frac{1}{\Gamma^-}
\]

\[
\tau_{K\pi} = \tau(D^0 \rightarrow K^- \pi^+) = \frac{1}{\Gamma_D}
\]

$y_{CP} \neq 0 \Rightarrow$ Mixing

if CP conserved $\Rightarrow y_{CP} \equiv y$
Two sources for $D^0$
**y_{CP} at LHC-b**

D\* Tag leads a clean sample

Easily able to see the two production methods to get expected lifetime
**\(y_{CP} \text{ at LHC-b}**

KK mode is also clean

\[ y_{CP} = (5.5 \pm 6.3 \text{(stat)} \pm 4.1 \text{(sys)}) \times 10^{-3} \]

Lifetime distribution is lovely. Systematic uncertainty dominated by secondary like background. Only tiny fraction of data.
\( \gamma_{CP} \) at Belle

- Preliminary analysis of full data set

<table>
<thead>
<tr>
<th>channel</th>
<th>KK</th>
<th>K( \pi )</th>
<th>( \pi \pi )</th>
</tr>
</thead>
<tbody>
<tr>
<td>yield</td>
<td>242k</td>
<td>2.61M</td>
<td>114k</td>
</tr>
<tr>
<td>purity</td>
<td>98.0%</td>
<td>99.7%</td>
<td>92.9%</td>
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</tbody>
</table>
$yCP$ at Belle

**SVD1**

3-layer SVD
153 fb$^{-1}$
1999-2003

**SVD2**

4-layer SVD
823 fb$^{-1}$
2003-2010
$y_{CP}$ at Belle

$y_{CP} = (11.1 \pm 2.2$ (stat) $\pm 1.1$(sys)) x 10^{-3}$

<table>
<thead>
<tr>
<th>source</th>
<th>$\Delta y_{CP}$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>acceptance</td>
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<tr>
<td>SVD misalignments</td>
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<tr>
<td>mass window position</td>
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<tr>
<td>background</td>
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<tr>
<td>resolution function</td>
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<tr>
<td>binning</td>
<td>0.021</td>
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<tr>
<td>sum in quadrature</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Sample

- SVD1: $1.46 \pm 0.60$
- SVD2: $1.06 \pm 0.23$
- SVD1 + SVD2: $1.11 \pm 0.22$

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\textbf{yCP at BaBar}

- Preliminary results from full data sample

Use of untagged $K\pi$ for $x4$ in statistics. New is combined tagged and untagged analysis.
yCP at BaBar

\[ \text{\( D^{*+} \) at BaBar} \]

\[ \begin{align*}
\text{\( D^{*+} \pi\pi \)} & : \quad \text{Data, Signal, Comb., Charm} \\
\text{\( D^{*+} KK \)} & : \quad \text{Data, Signal, Comb., Charm} \\
\text{\( D^{*\pm} K\pi \)} & : \quad \text{Data, Signal, Comb., Charm} \\
\text{\( \bar{D}^{\mp} K\pi \)} & : \quad \text{Data, Signal, Comb., Charm} \\
\end{align*} \]

\[ \begin{align*}
\text{CP+ lifetimes} & : \quad \tau^+ = (405.69 \pm 1.25) \text{ fs} \\
& \quad \bar{\tau}^+ = (406.40 \pm 1.25) \text{ fs} \\
\text{D^0 lifetime} & : \quad \tau_{K\pi} = (408.97 \pm 0.24) \text{ fs} \\
\end{align*} \]

[stat error only]
$y_{CP}$ at BaBar

| Category           | Fit Variation                           | $\Delta |y_{CP}|$ (%) |
|--------------------|-----------------------------------------|-----------|
| Fit Region         | width of sigBox                          | 0.057     |
|                    | position of sigBox                       | 0.005     |
| Signal             | KKUnet $\sigma_t$ signal PDF             | 0.022     |
|                    | Mistag Fraction                          | 0.0       |
|                    | $D^0$ Fraction in KKUnet                 | 0.001     |
| Charm              | lifetimes                                | 0.042     |
|                    | yields                                   | 0.016     |
|                    | yields                                   | 0.043     |
| Combinatorial      | weighting parameter                      | 0.004     |
|                    | PDF from sidebands                       | 0.066     |
| Selection          | $\sigma_t$ cut                           | 0.052     |
|                    | adjudication                             | 0.028     |
|                    | Total Systematic Error                   | 0.124     |

$y_{CP} = (7.2 \pm 1.8\text{ (stat)} \pm 1.2\text{ (syst)}) \times 10^{-3}$
Conclusion

• Preliminary full data results from BaBar and Belle for $y_{CP}$
• Impressive initial results from LHC-b; likely to dominate in the next few years
• Desperate for theory guidance on what we are learning with the observations of mixing and CP-violation in charm.
HFAG Average March 2012

- HFAG Average = \((10.6 \pm 2.1) \times 10^{-3}\)
- Includes LHC-b

- Preliminary BaBar = \((7.2 \pm 2.2) \times 10^{-3}\)
- Preliminary Belle = \((11.1 \pm 2.5) \times 10^{-3}\)