Physics at LHCb
(Discussion)

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22 October 2003
$10^{36}$ Super B-factory workshop
The angle $\gamma$ by different methods

In plenary talk I went through three different methods for measuring $\gamma$.

1. $B_s \rightarrow D_s^{\pm} K^\mp$, $B_d \rightarrow D^{\ast\pm} \pi^\mp$
2. $B_d \rightarrow D^0 K^0$
3. $B_d \rightarrow \pi^+ \pi^- / B_s \rightarrow K^+ K^-$

As a start for discussion I will deal here with how we might solve ambiguous solutions from above analysis by:

- Combining different analysis.
- Use $B_d$ and $B_s$ decays at the same time.
- Adding extra information.
- Untagged $B_s \rightarrow D_s^{\pm} K^\mp$ decays.
Reminder: $B_s \rightarrow D_s^{\pm} K^{\mp}$, $B_d \rightarrow D_s^{\ast\pm} \pi^{\mp}$ [Alexan, Dunietz, Kayser]

Asymmetry $A_f(t)$ for decay into non-$CP$ eigenstate $f$.
Both $B$ and $\bar{B}$ can decay into $f$.

\[ A_f(t) = \frac{A_{dir} \cos(\Delta m t) + A_{mix} \sin(\Delta m t)}{\cosh(\Delta \Gamma t/2) + A^\Delta \Gamma \sin(\Delta \Gamma t/2)} \]

($\Delta \Gamma$ from here)

\[ A^\Delta \Gamma = \frac{2 \Re(\eta)}{1 + |\eta|^2} \]

\[ |\eta|^2 \text{ from here} \]

\[ |\eta|\sin(\delta + (\phi + \gamma)) \text{ from here} \]

\[ A_{dir} = \frac{1 - |\eta|^2}{1 + |\eta|^2} \]

\[ A_{mix} = \frac{2 \Im(\eta)}{1 + |\eta|^2} \]

(\[ \text{We get } \delta - (\phi + \gamma) \text{ from } CP \text{ conjugate of } f \])

Phase $\gamma$

Interference between two tree diagrams so we measure $\gamma$ unaffected by new physics.
Ambiguities in extraction of $\gamma$

For $B_d \rightarrow D^{*\pm} \pi^\mp$ we only measure $\sin(\delta \pm (\phi_d + \gamma))$

Will keep an 8-fold ambiguity.

For the $\gamma$ measurement from $B_d \rightarrow \pi^+\pi^- / B_s \rightarrow K^+K^-$ this is a minor problem – but measurement might be affected by new physics.

What about the $B_s \rightarrow D_s^{\pm}K^\mp$ channel?

If $\Delta\Gamma_s = 0$ there is an 8-fold ambiguity as well.

If $\Delta\Gamma_s \neq 0$ only 2-fold ambiguity but still local minima at non-true values of $\gamma$.

Effect still under study.
Ambiguities for $B_d \to D^{*\pm} \pi^\mp$

The multiple solutions for $\beta=23^\circ$, $\gamma=65^\circ$ and $\delta=0$.

Only for partially reconstructed channel.

Solutions in this conceptual example overlap in groups of 4.

We may need other information on $\gamma$ to confirm/exclude the Standard Model.
Combining $\gamma$ measurements

Since $B_d \rightarrow D^{*\pm} \pi^\mp$ includes $\phi_d$ and $B_s \rightarrow D_s^{\pm} K^\mp$ includes $\phi_s$, the ambiguous solutions are at different places.

A combined analysis can pick the correct solution with only 2-fold ambiguity.
Use of untagged $B_s \to D_s K/\pi$ decays

At hadron machines any method using untagged decays has an upfront advantage.

$$\Gamma(B/\bar{B} \to D_s^- K^+) \propto \cosh \left( \frac{\Delta \Gamma}{2\Gamma} t \right) - A_{\Delta \Gamma} \sinh \left( \frac{\Delta \Gamma}{2\Gamma} t \right) e^{-t}$$

$$A_{\Delta \Gamma} = \frac{2 \Re(\eta)}{1 + |\eta|^2}$$

This will give us information on $\cos(\phi_s + \gamma + \delta)$ and additional statistics for $\Delta \Gamma/\Gamma$.

$$|\eta|^2 = \frac{2\Gamma(B/\bar{B} \to D_s^{\pm} K^{\mp})}{\Gamma(\bar{B} \to D_s^+ \pi^-) + \Gamma(B \to D_s^- \pi^+)} \frac{\lambda^2}{1 - \lambda^2} \left| \frac{f_K}{f_\pi} \right|^2 - 1$$

Will give extra information on $|\eta|^2$ with very small theoretical uncertainty from factorisation.

These two methods are not viable for $B_d \to D^{*\pm} \pi^{\mp}$.
U-spin symmetry for $B_s \to D_s K / B_d \to D\pi$ [Fleischer hep-ph/0304027]

If we analyse decays of the same spin state from both Bs and Bd we can use U-spin symmetry.

Look at $B_s \to D_s \pm K^\mp$, $B_d \to D^{\pm} \pi^{\mp}$ or $B_s \to D_s^{\pm} K^\mp$, $B_d \to D^{*\pm} \pi^{\mp}$.

We have the exact relationship:

$$
\frac{\tan(\phi_d + \gamma)}{\tan(\phi_s + \gamma)} = \left[ \frac{\tan \delta_d}{\tan \delta_s} \right] \frac{\left\langle A_{d}^{\text{mix}} \right\rangle + l \left\langle A_{d}^{\text{mix}} \right\rangle_-}{\left\langle A_{s}^{\text{mix}} \right\rangle + l \left\langle A_{s}^{\text{mix}} \right\rangle_-}
$$

$$
\left\langle A_{d(s)}^{\text{mix}} \right\rangle_\pm = \frac{1}{2} \left| A_{d(s)}^{\text{mix}}(B_s \to D_s^{\pm} \pi^{-}(K^-)) \pm A_{d(s)}^{\text{mix}}(B_s \to D_s^{-} \pi^{+}(K^+)) \right|
$$

In one strategy we assume that $\delta_d = \delta_s$ so the above reduces to

$$
\frac{\tan(\phi_d + \gamma)}{\tan(\phi_s + \gamma)} = \frac{\left\langle A_{d}^{\text{mix}} \right\rangle + l \left\langle A_{d}^{\text{mix}} \right\rangle_-}{\left\langle A_{s}^{\text{mix}} \right\rangle + l \left\langle A_{s}^{\text{mix}} \right\rangle_-}
$$

Notice that we do not need any knowledge of $|\eta|^2$ here for the $B_d$ decay.
Other physics at LHCb

$B_c$ physics

Lifetime and branching fractions accessible.

Clean $\gamma$ measurement from $B_c \to D D_s$ looks impossible.

The angle $\phi_d+2\gamma (\alpha)$ from $B_d \to \pi^+\pi^-\pi^0$.

Studies indicate a yield of 4.4k events per year with $B/S<7$.

No adverse effect from rejecting events with low energy $\pi^0$ from Dalitz analysis.

Rare decays

See talk by Patrick Koppenburg in Working Group 1.

New physics in $b \to s$ penguin processes.

$B_s \to \phi\phi$, $B_d \to \mu^+\mu^-K^{*0}$, $B_d \to K^{*0}\gamma$, and $B_d \to K^0_s\phi$ channels will all be affected by this and can be triggered and reconstructed with LHCb.