Measurements of $B \rightarrow DK$ decays to constrain the CKM unitarity triangle angle $\gamma$ at LHCb

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Outline

• Motivation and methods
• Results from measurements of $B^+ \rightarrow D K^+$ decays
• $\gamma$ combination
• Additional measurements from:
  – $B_s \rightarrow D_s K$
  – $B_s \rightarrow D^0 \phi$
Why measure $\gamma$?

- Potential probe of new physics through CKM metrology
- Small theoretical ($10^{-7}$) but large experimental uncertainty
- Current measurements have large experimental uncertainty:
  - CKMFITTER $\gamma = 68.0^{+8.0}_{-8.5}$
  - UTFIT $\gamma = 70.8 \pm 7.8^\circ$
  - including latest LHCb results
Measurement from $B^- \rightarrow DK^-$

- Tree level measurement
- No penguin contributions so theoretically clean
- $B \rightarrow D\pi$ also used but with smaller sensitivity

\[ \begin{align*}
B^- & \rightarrow D^0 \bar{u} \quad \text{Favoured} \\
B^- & \rightarrow K^- \bar{u} \quad \text{Suppressed}
\end{align*} \]
Measurement from $B^- \to D K^-$

$D$ final states and methods


ADS: $f_D = K\pi$ or $K\pi\pi\pi$ [Atwood-Dunietz-Soni] PRL 78,257(1997), PRD 63,036005(2001)


$\gamma$ from $B \to DK$ at LHCb
GLW and ADS observables are built as ratios of branching fractions - many systematic uncertainties cancel

**CP asymmetries**

\[ A_h^f \equiv \frac{\Gamma (B^- \to f_D h^-) - \Gamma (B^+ \to f_D h^+)}{\Gamma (B^- \to f_D h^-) + \Gamma (B^+ \to f_D h^+)} \]

**K/π ratios**

\[ R_{K/\pi}^f \equiv \frac{\Gamma (B^- \to f_D K^-) + \Gamma (B^+ \to f_D K^+)}{\Gamma (B^- \to f_D \pi^-) + \Gamma (B^+ \to f_D \pi^+)} \]

**ADS suppressed/favoured ratio**

\[ R_h^{f \pm} \equiv \frac{\Gamma (f_d h^\pm)^{su}}{\Gamma (\overline{f}_d h^\pm)^{fa}} \]
GLW/ADS with $B \to Dh$, $D \to$ two-body

Large asymmetry in $B \to DK$: $A_{\text{ADS}} = (-52 \pm 15 \pm 2)\% \ (4\sigma)$

Hint of asymmetry in $B \to D\pi$: $A_{\text{ADS}} = (14.3 \pm 6.2 \pm 1.1)\% \ (2.4\sigma)$

$\gamma$ from $B \to DK$ at LHCb
Hint of asymmetry in $B \to D K$: $A_{\text{ADS}} = (-42 \pm 22)\%$

Hint of asymmetry in $B \to D \pi$: $A_{\text{ADS}} = (13 \pm 10)\%$
GGSZ with $B^+ \rightarrow DK^+$, $D \rightarrow K_s h^+ h^-$

- Exploits the interference between the $D \rightarrow K_s KK$ and $D \rightarrow K_s \pi\pi$ Dalitz plots.
- The rich resonance structure provides a powerful measurement method.

- Published results using 2011 data sample [PLB 718(2012) 43]
- Preliminary results using 2012 data sample [LHCB-CONF-2013-004]
**GGSZ with \( B^+ \rightarrow DK^+ \)**

Extraction of \( \gamma \) requires knowledge of the decay amplitude and phase \( \delta_D \) across the Dalitz plot.

Use either:
- Model of decay amplitude
- External measurements (model independent)

\[ m_\pm = m(K_s h^\pm) \]

\( \gamma \) from \( B \rightarrow DK \) at LHCb
Binned approach

- Use discrete measurements of $\delta_D$ from CLEO-c to give $c_i$ and $s_i$ [PRD82(2010)112006]
- Their binning is chosen to optimise sensitivity of $\gamma$

$$N (B^\pm)_{+i} = h_B \varepsilon_i [K_{-i} + (x^2 + y^2) K_{+i} + 2 \sqrt{K_i K_{-i}} (x_i c_i \mp y_i s_i)]$$

$x = r_B \cos (\delta_B \pm \gamma)$$
$y = r_B \sin (\delta_B \pm \gamma)$

$x$ and $y$ are extracted from a simultaneous fit to yields in each bin

The $K_sKK$ sample adds two additional bins

$\gamma$ from $B \to DK$ at LHCb
GGSZ results

2011 data

\[ \gamma = \left( 44^{+43}_{-38} \right)^{\circ} \]
\[ r_B = 0.07 \pm 0.04 \]

2012 data

\[ \gamma = (57 \pm 16)^{\circ} \]
\[ r_B = 0.09 \pm 0.02 \]

2011+2012 data

\[ x_+ = (-8.7 \pm 3.1 \pm 1.6 \pm 0.6) \times 10^{-2} \]
\[ x_- = (5.3 \pm 3.2 \pm 0.9 \pm 0.9) \times 10^{-2} \]
\[ y_+ = (0.1 \pm 3.6 \pm 1.4 \pm 1.9) \times 10^{-2} \]
\[ y_- = (9.9 \pm 3.6 \pm 2.2 \pm 1.6) \times 10^{-2} \]

\( \gamma \) from B\( \rightarrow \)DK at LHCb
B$^+ \rightarrow$ Dh$^+$ γ combination

- 2011 data only (1 fb$^{-1}$)
- First combination to include B$^+ \rightarrow$Dπ$^+$
- Result corrected for correlations between systematic uncertainties and D meson mixing

$\gamma$ from B→DK at LHCb

B$^+ \rightarrow$DK$^+$ only
B$^+ \rightarrow$Dπ$^+$ only
B$^+ \rightarrow$DK$^+$ and B$^+ \rightarrow$Dπ$^+$

B$^+ \to DK^+$ $\gamma$ combination update

Combination uses:
- 1 fb$^{-1}$ 2011 ADS/GLW
- 3 fb$^{-1}$ 2011+2012 GGSZ

$\gamma = (67 \pm 12)^\circ$ preliminary

Best measurement of $\gamma$ from a single experiment

BaBar: $\gamma = (69^{+17}_{-16})^\circ$
Belle: $\gamma = (68^{+15}_{-14})^\circ$

Future update of ADS/GLW to 3 fb$^{-1}$ will improve precision further
Time-dependent study of $\mathrm{B}_s \to \mathrm{D}_s \mathrm{K}$

- Two final states, $\mathrm{D}_s^+ \mathrm{K}^-$ and $\mathrm{D}_s^- \mathrm{K}^+$, both accessible to $\mathrm{B}_s$ and $\bar{\mathrm{B}}_s$
- CP violation in the interference of decays with and without mixing
- Sensitive to $\gamma - 2\beta_s$
- Time-dependent analysis and flavour-tagging required
- Unique to LHCb

\[
\begin{align*}
C &= 1.01 \pm 0.50 \pm 0.23 \\
S_f &= -1.25 \pm 0.56 \pm 0.24 \\
S_{\bar{f}} &= 0.08 \pm 0.68 \pm 0.28 \\
D_f &= -1.33 \pm 0.60 \pm 0.26 \\
D_{\bar{f}} &= -0.81 \pm 0.56 \pm 0.26
\end{align*}
\]

- First measurement of the CP parameters in $\mathrm{B}_s \to \mathrm{D}_s \mathrm{K}$ with 1$\text{fb}^{-1}$
- Main systematic uncertainties:
  - fixed parameters ($\Gamma_s, \Delta\Gamma_s, \Delta m_s$)
  - Flavour tagging calibration
- Extraction of $\gamma$ is sensitive to correlations – work in progress

$\gamma$ from $\mathrm{B} \to \mathrm{DK}$ at LHCb
$B^0_s \rightarrow D^0 \phi$

- $B^0_s \rightarrow D^0 \phi$ time-dependent is sensitive to $\gamma$ and $\beta_s$
- Both decays are colour-suppressed
- Time-integrated method also available with good potential sensitivity

First observation of $BF(B^0_s \rightarrow D^0 \phi) = [2.3 \pm 0.4 \text{ (stat.)} \pm 0.2 \text{ (syst.)} \pm 0.5 \text{ (norm.)}] \times 10^{-5} > 6\sigma$

First step: measurement of branching fraction wrt $B_s \rightarrow D^0 K^0$
Summary

- LHCb measurement of $\gamma$ from 2011 data 1 fb$^{-1}$
  - First measurement to include contribution from $B^- \rightarrow D\pi^-$
  - Good agreement with similar sensitivity to B factories
- Partial update with 3 fb$^{-1}$ of data for GGSZ measurement leads to best single-experiment measurement

$$\gamma = (67 \pm 12)^\circ$$ preliminary

- Precision will keep on improving with ADS/GLW 3 fb$^{-1}$ update and with the addition of other channels to the combination
Backup slides
Time-dependent study of $B_s \rightarrow D_s K$

Signal yield = 1390±98
γ combination update

Profile likelihood contours, separately for the B→DK GGSZ analysis (blue, partly-dashed contours) using 3 fb$^{-1}$ of data, and the B→DK part of the GLW/ADS analysis (orange, solid contours) using 1 fb$^{-1}$ of data. The contours are the usual 1σ and 2σ contours. The markers correspond to the best fit values.