$\gamma (\varphi_3)$ from $B \to DK$ and friends – where we are and what's next?

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2\textsuperscript{nd} B2TIP meeting; Krakow

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Importance of $\gamma$ from $B \to DK$

- $\gamma$ plays a unique role in flavour physics
  - the only CP violating parameter that can be measured through tree decays (*)
- A benchmark Standard Model reference point
  - doubly important after New Physics is observed

\[ \propto V_{cb} V_{us}^* \]

\[ \propto V_{ub} V_{cs}^* \]

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Variants use different B or D decays require a final state common to both $D^0$ and $\bar{D}^0$
Essential to know the SM before we can go beyond the SM.
The GLW method


Common final state for $D^0$ and $\bar{D}^0$ – CP eigenstates
- CP even: $K^+K^-$, $\pi^+\pi^-$
- CP odd: $K_S\pi^0$, $K_S\eta$, $K_S\phi$ (see later), $K_S\omega$

these are challenging for LHCb
GLW results

$D_{CP} K A_{CP}$

- **BaBar**
  - PRD 82 (2010) 072004
- **Belle**
  - LP 2011 preliminary
- **CDF**
  - PRD 81 (2010) 091105(R)
- **LHCb**
  - PLB 712 (2012) 203
- **Average**
  - HFAG

$0.25 \pm 0.06 \pm 0.02$

$0.29 \pm 0.06 \pm 0.02$

$0.39 \pm 0.17 \pm 0.04$

$0.14 \pm 0.03 \pm 0.01$

$0.19 \pm 0.03$

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γ from $B \to DK$

p.s. please publish these results!
Subtleties of GLW

- Over the last few years, considerable effort expended to understand how to deal with % level (or smaller) effects
  - Possible CPV in SCS D decays
    -> report results for $K^+K^-$ and $\pi^+\pi^-$ separately
  - Charm mixing effects
    -> understand D decay-time acceptance effects
  - CPV/regeneration effects in $K^0$ system
    -> still negligible
- The drive to control these effects has come from the desire to include results with $B \rightarrow D\pi$ (smaller $r_B$ -> larger subleading effects)
  - Even if $B \rightarrow D\pi$ does not contribute much statistically to the $\gamma$ combination, it is worth including to ensure control of systematic uncertainties
Can we use more D decays?

- GLW analyses to date have used
  - CP even
    - $K^+K^-$, $\pi^+\pi^-$
  - CP odd
    - $K_S\pi^0$, $K_S\eta$, $K_S\phi$ (see later), $K_S\omega$

- No other experimentally accessible pure CP eigenstates ...
  - are there “quasi CP eigenstates”?
  - can we handle them with a “quasi GLW analysis”?
$D \rightarrow \pi^+ \pi^- \pi^0$

- Seminal Dalitz plot analysis from BaBar (PRL 99 (2007) 251801)
  - Gives the parameter $x_0 = 0.850$ (without uncertainty)
  - Relation to fractional CP-even content: $x_0 = 2F_+ - 1$

- Effect of CP-even dominance included in modified GGSZ-type analysis
  - Message that simpler quasi-GLW analysis gives good sensitivity was not clear

- Noted that decay is almost pure isospin 0 (PR D78 (2008) 014015)
D → π⁺π⁻π⁰ with CLEO-c data

- Exploit Ψ(3770) → DD decays for direct measurement of CP content

\[ F_+ = 0.973 \pm 0.017 \]
Aside on $D \rightarrow \pi^+\pi^-\pi^0$

- It seems remarkable that $D \rightarrow \pi^+\pi^-\pi^0$ is so close to pure CP-even
  - no known a priori reason for this to be so
  - n.b. $K \rightarrow \pi^+\pi^-\pi^0$ is ~pure CP-odd (but this is understood)

- How about $B \rightarrow \pi^+\pi^-\pi^0$?
  - if this is almost pure CP-eigenstate, what happens to the Snyder-Quinn method to measure $\alpha$?
Can we use more D decays?

- GLW analyses to date have used
  - CP even
    - $K^+K^-$, $\pi^+\pi^-$
    - $\pi^+\pi^-\pi^0$ ($F_+ = 0.973 \pm 0.017$), $K^+K^0\pi^-$ ($F_+ = 0.732 \pm 0.055$), $\pi^+\pi^-\pi^+\pi^-$ ($F_+ = 0.737 \pm 0.028$)
  - CP odd
    - $K_s\pi^0$, $K_s\eta$, $K_s\phi$ (see below), $K_s\omega$
- Other 3 body modes have more complicated CP-content
  - $K_sK^+K^-$, $K_s\pi^+\pi^-$ both have $F_+ \sim 0 \rightarrow$ GGSZ analysis
  - n.b. $K_sK^+K^-$, has $\sim 50\%$ CP-odd ($K_s\phi$) + $\sim 50\%$ CP-even (the rest)
First quasi-GLW analysis with $D \to \pi^+\pi^-\pi^0 \& K^+K^-\pi^0$

- LHCb-PAPER-2015-014 (arXiv:1504.05442) (see Sneha's talk for details)

Expect these modes to be useful for Belle II
Beyond $B \rightarrow DK$

• Attractive feature of $B \rightarrow D*K$
  - Effective CP-flip between $D^* \rightarrow D\pi^0$ and $D^* \rightarrow D\gamma$
    • PRD70 (2004) 091503
  - Additional sensitivity, but also necessitates good separation between the two $D^*$ decays

• Attractive feature of $B \rightarrow DK^{*0}$
  - Interference between $D_2^{*}$ and $K^{*0}$ resonances resolves ambiguities
    • PRD 79 (2009) 051301(R), PRD 80 (2009) 092002
Extension to $B \to D\pi K$ decays

- Powerful extension of the method exploits additional sources of interference that occur in multibody decays
  - $B^0 \to D(\pi^-K^+)$ decays can have CP violation
  - $B^0 \to (D\pi^-)K^+$ decays have no CP violation
- Provides ideal reference amplitude from which to determine relative phases via interference between different resonances on the Dalitz plot

Toy example containing $K^*(892)^0$, $K_2^*(1430)^0$, $D_2^*(2460)^-$ effects of spin clearly visible

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Interference region

effects of spin clearly visible
B → DπK Dalitz plot

- LHCb-PAPER-2015-017 (arXiv next week)
  - use D → Kπ decays to determine Dalitz plot model for favoured b → c amplitude

n.b. axes flipped c.f. previous slides
The $B \to D\pi K$ Dalitz plot method

- Basic idea is that pion from $D^*_2$ decay tags flavour of that resonance
- Amplitude for $B^0 \to D^*_2 K$ is same, independent of $D$ decay used
- Allows direct reconstruction of GLW triangle
- How is the sensitivity?
  - PRD 80 (2009) 092002 claims similar to $B \to D K$
  - will need to wait and see …
  - (n.b. $r_B(DK^0) = 0.240^{+0.055}_{-0.048}$ – LHCb PRD 90 (2014) 112002)

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$\gamma$ from $B \to D K$
Summary

• Despite many people thinking about $\gamma$ for many years, there are still good new ideas emerging

• The best sensitivity comes from combining results from all of $B \rightarrow DK$ and friends

• Many channels make useful contributions
  – including several that I did not discuss today
  – still a lot of work (potential improvement) to arrive at ultimate precision on $\gamma$ for both LHCb & Belle II

• Measurements from BESIII on $\Psi(3770) \rightarrow D\bar{D}$ are needed