Measurements of the CP angle $\gamma$ using $B \rightarrow DK$ decays and an amplitude model of $D \rightarrow K_{S}hh$ decays at LHCb.

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Motivation

1 fb$^{-1} \ B^{\pm} \rightarrow DK^{\pm}, \ D \rightarrow (K_{S}\pi^{+}\pi^{-})$

3 fb$^{-1} \ B^{0} \rightarrow DK^{*0}, \ D \rightarrow (K_{S}\pi^{+}\pi^{-})$
(in progress)

Summary/Outlook
Motivation
Constraining the Standard Model

- $\rho$ from trees is 'standard candle' of CKM - $(\Delta \gamma_{\text{theory}}/\gamma \sim 10^{-7})$.
- New Physics: compare ($\gamma$ from trees) with ($\gamma$ from loops).

68% CL: $\gamma_{\text{direct}} = \left( 73.2^{+6.3}_{-7.0} \right) ^\circ$ (CKMFitter)
\[ \gamma \equiv \arg \left( -\frac{V_{ud} V_{ub}^*}{V_{cd} V_{cb}^*} \right) \]

- Reconstruct full $B$-decay.
  - Create and measure $B$ mesons in VELO.
  - Identify final state particles in RICH.

68% CL: \[ \gamma = (73^{+9}_{-10})^\circ \]

arXiv: 1411.4600
$1 fb^{-1} \; B^\pm \rightarrow DK^\pm, \; D \rightarrow (K_S \pi^+\pi^-)$

\( B^{\pm} \rightarrow DK^{\pm} \), \( D \rightarrow K_{S}^{0}\pi^{+}\pi^{-} \).

\( D \) can be \( D^{0} \) or \( \bar{D}^{0} \) → interference!

\( \gamma \equiv \arg \left( -\frac{V_{ud}V_{ub}^{*}}{V_{cd}V_{cb}^{*}} \right) \)

Fit the phase space of the \( D \) decay to extract \( \gamma \).

\[
A \left( B^{-} \rightarrow (K_{S}^{0}\pi^{+}\pi^{-})_{D}K^{-} \right) \propto \left( A(D^{0}) + r_{B}e^{i(\delta_{B}-\gamma)}A(\bar{D}^{0}) \right)
\]

Need matrix element for three-body \( D \) decay - use non-fundamental theory of resonances:

\( D \rightarrow rc \), \( r \rightarrow ab \)

‘Model dependent’; choice of resonances and parameterizations.

\[
m^{2}_{\pm} = \left( P_{0}^{\mu} + P_{\pm}^{\mu} \right)^{2}
\]
Select candidate events using rectangular cuts.

Fit $B^\pm$ mass spectrum for yields.

Fit Dalitz plane of $D$ decay using resonance models.

Use $B^\pm \to D\pi^\pm$ as control mode for efficiency.
Results

\( x_\pm = +0.027 \pm 0.044^{+0.010}_{-0.008} \pm 0.001 \)
\( y_\pm = +0.013 \pm 0.048^{+0.009}_{-0.007} \pm 0.003 \)
\( x_\mp = -0.084 \pm 0.045 \pm 0.009 \pm 0.005 \)
\( y_\mp = -0.032 \pm 0.048^{+0.010}_{-0.009} \pm 0.008 \)

- Third error is systematic due to choice of amplitude model.

\[ \gamma = \left( 84^{+49}_{-42} \right)^\circ \]

arXiv:1407.6211

- See Faye's talk (next up) for model-independent result.
3 fb$^{-1}$ $B^0 \rightarrow D K^{*0}$, $D \rightarrow (K_S \pi^+ \pi^-)$

(in progress)
Introduction; \( B^0 \rightarrow DK^{*0} \rightarrow (K_S\pi^+\pi^-)(K^+\pi^-) \)

- Use as many modes as possible to constrain \( \gamma \).

\[
\begin{align*}
\bar{b} & \quad V_{ub} & \quad \bar{u} \\
\quad & \quad c & \quad \bar{s} \\
d & \quad & \quad d
\end{align*}
\]

\[
\begin{align*}
\bar{b} & \quad V_{cb} & \quad \bar{c} \\
\quad & \quad u & \quad \bar{s} \\
d & \quad & \quad d
\end{align*}
\]

- Lower branching fraction than \( B^{\pm} \rightarrow DK^{\pm} \).
- But - \( r_B \) is larger in this case - so more prominent interference.

**BaBar**
- \( \sim 400 fb^{-1} \) of data.
- \( 39 \pm 9 \) signal events.
- \( \delta \gamma = 56^\circ \) at 68\% CL.

\( \text{Phys. Rev. D 79, 072003 (2009)} \)

**Belle**
- Analysis underway using full dataset.
- Expect public results soon...

- Selection is more difficult due to more final state particles → use MVA-based event selection.
Selection

- BDT vs NeuroBayes vs Fisher vs ...
- Multiple networks to discriminate against different backgrounds?
  - e.g. $D_{\rho}^0$, $D^* K^*$ part. reco.
- Use ‘crossed’ MVA’s, to train within the fitted mass region?
- Include MVA’s with PID input variables?

- In the end, use crossed BDT’s plus rectangular PID cuts.
- Final working point tuned using toy sensitivity study and stochastic figure-of-merit optimization.

$$\text{hybrid FOM} = \frac{S^2}{(S + B)^{3/2}} = \frac{S}{S + B} \times \frac{S}{\sqrt{S + B}}$$
Current Status

- Selection finalized.
- Nominal mass fit performed.
- Efficiency obtained from MC, including corrections for MC-data differences.
- Nominal Dalitz fit performed; result still blinded.
- Evaluating systematics.

\[ \text{Sig. yield} = 106 \pm 12 \]
The more modes studied, the better $\gamma$ can be constrained.

Can combine multiple modes into one single fit:

**Combined fit for $\gamma$**

$$ B \rightarrow D^{(*)} \pi, D^{(*)} K^{(*)} $$

$$ D \rightarrow (K_S h^+ h^-), \quad h = \pi, K $$

- Each mode has sensitivity to $\gamma$, whilst hadronic parameters differ for each.
- A single, combined fit reduces the number of free parameters.
- Should give a more robust result than statistically combining separate results from each mode.
Backup
$B^0 \rightarrow DK^*0 \rightarrow (K_S\pi^+\pi^-)(K^+\pi^-)$

- Initial $B$-decay is three-body.
- $K^*$ is one resonance within the $B$ Dalitz plane of $(DK^+\pi^-)$.
- In reconstructing a $K^*$ and placing a mass cut on it, we select only a sub-region of the final state phase space.
- So we must only integrate $|A|^2$ over this sub-region.

$$P(A, z, \kappa) = |A|^2 + |z|^2|\overline{A}|^2 + 2\kappa \text{Re}\{zA^*\overline{A}\}$$

$$A = A(D^0), \overline{A} = A(D^0), \quad z = r_B e^{i(\delta_B \pm \gamma)}$$