Flavour in the era of the LHC

A Model-Independent Analysis of New Physics Contributions in $|\Delta F| = 2$ transitions

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Outline - New Physics in $|\Delta F|=2$ transitions

Part I. Introduction.

Part II. Exploring New Physics in $B_d$ mixing.
   Basic inputs.
   Adding $\gamma$ and $\alpha$ measurements.
   Adding $a_{SL}$ contribution.


Part IV. Prospective for New Physics in the $B_s$ mixing.
Quality of CKM Standard fit

Standard Model accommodates *successfully* all the present flavour data.

There is no need *a priori* for NP contributions in tree-mediated flavour changing processes.
Is there still room for new physics?

Follow the strategy developed in the paper:


Past & present attempts (a selection of)

Ciuchini et al., hep-ph/0307195
Bona et al., hep-ph/0509219

Assumption $\Leftrightarrow$ no NP in tree-mediated decay amplitudes:
$|V_{ub}|/|V_{cb}|$ and $\gamma$ are the main inputs constraining the CKM parameters.

Introduce NP in $\Delta B=2$ transitions accounted for model-independently through two additional parameters.

$$r_d^2 e^{i2\theta_d} = \frac{\left< B^0 | H^{\text{full \_ eff}} | \bar{B}^0 \right>}{\left< B^0 | H^{\text{SM \_ eff}} | \bar{B}^0 \right>}$$
- $|V_{ub}|, |V_{cb}| \leftrightarrow$ Remove $b \to s\gamma$ component from the inclusive $V_{ub}$ average
- $r_d^2 \Delta m_d$
- $\sin(2\beta + 2\theta_d)$
- $\cos(2\beta + 2\theta_d)$

- The SM value on $2\theta_d=0$ is at the border of the $CL_{Max}$ region.
- Shows slight disagreement between $V_{ub}$ and $\sin(2\beta)$.
- Any region with $2\theta_d > \pi/2$ is discarded.
Adding $\gamma$ measurements.

- $|V_{ub}| / |V_{cb}|$
- $r_d^2 \Delta m_d$
- $\sin(2\beta + 2\theta_d)$
- $\cos(2\beta + 2\theta_d)$
- $\gamma$ ($ADS + GLW + GGSZ$)

- $V_{ub}$ and $\gamma$ constrain the CKM parameters.
- Two solutions for NP parameters emerge.
Adding $\alpha$ measurements.

$|V_{ub}|/|V_{cb}|$

$r_d^2 \Delta m_d$

$\sin(2\beta + 2\theta_d)$

$\cos(2\beta + 2\theta_d)$

$\sin(2\beta + 2\theta_d + 2\gamma)$

The $\alpha$ constraint (w/o $\gamma$) displays also four solutions.

Reinforce the SM region but the preferred NP region is not the one defined by $\gamma$. 
\[ |V_{ub}|/|V_{cb}| \]
\[ r_d^2 \Delta m_d \]
\[ \sin(2\beta + 2\theta_d) \]
\[ \cos(2\beta + 2\theta_d) \]
\[ \gamma \ (ADS + GLW + GGSZ) \]
\[ \sin(2\beta + 2\theta_d + 2\gamma) \]

\( \gamma \) and \( \alpha \) are of major importance in constraining the NP parameters.

**NB:** \( \sin(2\beta+2\theta_d+\gamma) \) is not included. (almost no influence.)
NP in $B_d - \overline{B}_d$ mixing $a_{SL}$ in the game

\[
a_{SL} = -\text{Re} \left( \frac{\Gamma_{12}}{M_{12}} \right)^{SM} \frac{\sin 2\theta_d}{r_d^2} + \text{Im} \left( \frac{\Gamma_{12}}{M_{12}} \right)^{SM} \frac{\cos 2\theta_d}{r_d^2} \quad (\Gamma_{12}/M_{12} \text{ is considered here at Leading Order})
\]

Though the experimental precision is far from the prediction, $a_{SL}$ is a crucial input for constraining NP parameters. Only observable depending on both $r_d^2$ and $2\theta_d$.

\[
a_{SL} = -0.0026 \pm 0.0067 \quad (\text{HFAG 2005})
\]
NP parameters extraction

$\rightarrow |V_{ub}|/|V_{cb}|$
$\rightarrow r_d^2 \Delta m_d$
$\rightarrow \sin(2\beta + 2\theta_d)$
$\rightarrow \cos(2\beta + 2\theta_d)$
$\rightarrow \gamma \ (ADS + GLW + GGSZ)$
$\rightarrow \alpha \ \sin(2\beta + 2\theta_d + 2\gamma)$
$\rightarrow a_{SL}$

$\begin{align*}
\begin{cases}
  r_d^2 = 0.92^{+0.73}_{-0.23} \\
  2\theta_d = -5.3^{+3.2}_{-8.8} \ deg
\end{cases}
\end{align*}$

(Uncertainties are given at 1σ)

The NP solution at $\pi/2$ has 1-CL < 3%. 
Influence of non-pert. hadronic parameters in $\Delta m_d$

\[ \Delta m_d = \frac{G_F^2}{6\pi^2} \eta_B m_{B_d} f_{B_d} B_d m_W^2 S(x_t) |V_{td} V_{tb}^*| r_d^2 \]

- As far as the lattice uncertainties are considered, $f_{B_d}$ is the relevant parameter to improve.
- A factor 2 has important impact. A factor 10 is not decisive with the current experimental uncertainties of the observables.
Alternative parametrization of NP in $|\Delta B| = 2$

Isolate the pure NP contribution from (SM+NP) terms:

$$M_{12} = M_{12,SM} (1 + h_d e^{2i\sigma_d})$$

Agashe et al. hep-ph/0509117

$$\Delta m_d = |1 + h_d e^{2i\sigma_d}| \Delta m_d^{SM}$$

$$2\beta \rightarrow 2\beta + Arg(1 + h_d e^{2i\sigma_d})$$

$$a_{SL} = \text{Im}(\frac{\Gamma_{12}^{SM}}{M_{12}^{SM} (1 + h_d e^{2i\sigma_d})})$$

Without $\gamma, \alpha$ and $a_{SL}$ constraints

With $\gamma, \alpha$ and $a_{SL}$ constraints

$h_d = 0.08^{+0.65}_{-0.06}$
Allowing in addition NP in $K$-$K$ mixing (I)

$$r_K = \frac{\text{Im} \left< K^0 | H^{\text{full eff}} | \bar{K}^0 \right>}{\text{Im} \left< K^0 | H^{\text{SM eff}} | \bar{K}^0 \right>}$$

$\rightarrow |V_{ub}|/|V_{cb}|$

$\rightarrow r_d^2 \Delta m_d$

$\rightarrow \sin(2\beta + 2\theta_d)$

$\rightarrow \cos(2\beta + 2\theta_d)$

$\rightarrow \gamma \quad (ADS + GLW + GGSZ)$

$\rightarrow \alpha \sin(2\beta + 2\theta_d + 2\gamma)$

$\rightarrow a_{SL}$

$\rightarrow r_K \epsilon_K$

$(1\sigma)$

\[
\begin{align*}
    r_d^2 &= 0.92^{+0.76}_{-0.25} \\
    2\theta_d &= -4.8^{+4.1}_{-9.1} \text{ deg} \\
    r_K &= 1.09^{+0.45}_{-0.46}
\end{align*}
\]
Allowing in addition NP in K-K mixing (II)

The NP region at $2\theta_d = \pi/2$ in $B_d$ mixing implies also NP in $K$ mixing corresponding to $\epsilon_K < 0$.
The angle governing the mixing in the $B_s$ system is already known to good precision in the SM

\[ \sin(2\beta_s) = 0.0363 \pm 0.0025 \]

\[ \beta_s \approx \lambda^2 \eta + o(\lambda^4) \] can be extracted from the global Standard Model fit.

\[ \beta_s = \text{arg}\left( -\frac{V_{cb}V_{cs}^*}{V_{tb}V_{ts}^*} \right) \]
NP in $B_s$ mixing ($\Delta B=2$ and $\Delta S=2$) is accounted for model-independently through two additional parameters, akin to the $B_d$ system:

$$r_s^2 e^{i2\theta_s} = \frac{\left\langle B_s^0 | H^{\text{full}}_{\text{eff}} | B_s^0 \right\rangle}{\left\langle B_s^0 | H^{\text{SM}}_{\text{eff}} | B_s^0 \right\rangle}$$

- LHCb expected sensitivities correspond to $2 \text{ fb}^{-1}$
  (See Talks of O. Schneider & L. Fernandez):

  $\rightarrow \Delta m_s = 20.000 \pm 0.011 \text{ ps}^{-1}$ from $B_s \rightarrow D_s \pi$
  $\rightarrow A_{mix} = \sin(2\beta_s) = 0.036 \pm 0.028$

  from combined $B_s \rightarrow J / \Psi \Phi$, $B_s \rightarrow J / \Psi \eta$ and $B_s \rightarrow \eta_c \phi$
  $\rightarrow \gamma - 2\beta_s = 57 \pm 14 \text{ deg}$ from $B_s \rightarrow D_s K$
  $\rightarrow \gamma = 59 \pm 8 \text{ deg}$ from $B_d \rightarrow D^{(*)} K$

$\rightarrow r_s^2 \Delta m_s$
$\rightarrow \sin(2\beta_s + 2\theta_s)$
$\rightarrow \sin(2\beta_s + 2\theta_s - \gamma)$
\[
\begin{align*}
&\rightarrow |V_{ub}|/|V_{cb}| \\
&\rightarrow r_d^2 \Delta m_d \\
&\rightarrow \sin(2\beta + 2\theta_d) \\
&\rightarrow \cos(2\beta + 2\theta_d) \\
&\rightarrow \gamma \ (ADS + GLW + GGSZ) \\
&\quad \oplus \text{Adding LHCb sensitivity} \\
&\rightarrow \alpha \ \sin(2\beta + 2\theta_d + 2\gamma) \\
&\rightarrow a_{SL} \\
&\rightarrow r_K^2 \epsilon_K \\
&\rightarrow r_s^2 \Delta m_s \\
&\rightarrow \sin(2\beta_s + 2\theta_s) \\
&\rightarrow \sin(2\beta_s + 2\theta_s - \gamma)
\end{align*}
\]

\[r_s^2 = 1.01^{+0.11}_{-0.09}\]

\[2\theta_s = 0.1^{+1.6}_{-1.7} \text{ deg}\]
CONCLUSIONS

• $B_d$ mixing: which room for new physics? ... Not much.

• $K$ mixing: the only constraint is from $\epsilon_K$ ⇔ under constrained pb as far as specific NP phase & modulus are considered.

• $B_s$ mixing: LHCb will immediately see NP if $O(10^\circ)$. 

\[ \theta_s = 10^\circ \]
Main inputs to the fit

\[ |V_{ub}| \text{ (average)} = (4.15 \pm 0.12 \pm 0.23) \times 10^{-3} \]
\[ |V_{cb}| \text{ (incl)} = (41.58 \pm 0.45 \pm 0.58) \times 10^{-3} \]
\[ |V_{cb}| \text{ (excl)} = (41.4 \pm 2.1) \times 10^{-3} \]
\[ |\varepsilon_K| = (2.282 \pm 0.017) \times 10^{-3} \]
\[ \Delta m_d = (0.509 \pm 0.004) \text{ ps}^{-1} \]
\[ \sin(2\beta) = 0.687 \pm 0.032 \]
\[ \Delta m_K = (3.490 \pm 0.006) \times 10^{-12} \text{ MeV} \]
\[ B_K = 0.79 \pm 0.04 \pm 0.09 \]
\[ m_{K^+} = (493.677 \pm 0.016) \text{ MeV} \]
\[ f_K = 159.8 \pm 1.5 \text{ MeV} \]
\[ \eta_{tt} = 0.5765 \pm 0.0065 \]
\[ \eta_{ct} = 0.47 \pm 0.04 \]
\[ \eta_{B(MS)} = 0.551 \pm 0.007 \]
\[ f_{B_d}/B_d = (223 \pm 33 \pm 12) \text{ MeV} \]
\[ a_{SL} = -0.0026 \pm 0.0067 \]

\[ S^{+-}_{\pi\pi} = -0.50 \pm 0.12 \]
\[ C^{+-}_{\pi\pi} = -0.37 \pm 0.10 \]
\[ C^{00}_{\pi\pi} = -0.28 \pm 0.39 \]
\[ B_{\pi\pi, \text{all charge}} \] Inputs to isospin analysis
\[ S^{-\rho_{\rho L}} = -0.22 \pm 0.22 \]
\[ C^{-\rho_{\rho L}} = -0.02 \pm 0.17 \]
\[ B_{\rho_{\rho L, \text{all charge}}} \] Inputs to isospin analysis
\[ B \to \rho \pi \to 3\pi \] Time dependent Dalitz analysis

\[ B \to D^{(*)} K^{(*)(-)} \] Inputs to GLW, ADS & GGSZ analysis
II

γ measurements

![Diagram showing measurements]

Full frequentist treatment on MC basis

- D(*)K(*) GLW + ADS
- D(*)K(*) GGSZ
- Combined

CKM fit
Adding $B \rightarrow \tau \nu$

$BR(B^+ \rightarrow \tau^+\nu) = \frac{G_F^2 m_B \tau_B}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2$

With $\Delta m_d$, remove the $f_B$ dependence

- Powerful in the future for constraining the SM region.
- Potential annihilation by means of $H^+$ prevents for considering this input in the analysis.