Motivation

Setup

$B \longrightarrow J/\psi K, \phi K$

$B \longrightarrow \pi K$

Conclusion and outlook

Nonleptonic $b \longrightarrow s$ transitions: $\sin 2\beta$ and possible NP contributions

Martin Jung

in collaboration with Th. Feldmann and Th. Mannel

JHEP 0808:066,2008

Instituto de Física Corpuscular - IFIC, CSIC-UVEG, Valencia

SuperB Physics Workshop in Warwick 14/04/09

Outline

Motivation

Setup

$B \to J/\psi K$ and $B \to \phi K$

$B \to \pi K$

Conclusion and outlook

Motivation

- Last few years: shift of focus:
  CKM main source of (low energy) CP violation ✓
  ➥ What about new physics (NP)?

- NP expected at the TeV-scale
- Direct search will be performed at the LHC
- Flavour physics complementary tool
  - High sensitivity, even beyond LHC reach
  - But: Flavour data still compatible with SM
    ➥ Flavour Puzzzle

Tensions (?)

Small tensions in $|\Delta S| = |\Delta B| = 1$ - processes:

- $\sin 2\beta$ from $B \to J/\psi K_S$ vs. $\sin 2\beta$ from $|V_{ub}/V_{cb}|$ and $\Delta m_d/\Delta m_s$
- $\sin 2\beta$ from $B \to J/\psi K_S$ vs. $\sin 2\beta$ from $B \to \phi K_S$
  Note: Naive $b \to s\bar{s}s$ average compatible by now
- CP-Asymmetries in $B \to K\pi$ (?)

➥ Implications for possible NP Flavour Structure?

Apparently:

- Different effects in $(\sin 2\beta)_{J/\psi K}$ and $(\sin 2\beta)_{\phi K}$
- Deviations in direct CP asymmetries and BRs

➥ Assume NP in $|\Delta B| = |\Delta S| = 1$ amplitudes
Here: Neglect effects in mixing

(See however talk by Th. Mannel)

Strategy

Problem twofold:

- Understand SM hadronic process
- Determine NP influence

We explore $b \to s\bar{q}q$-processes the following way:

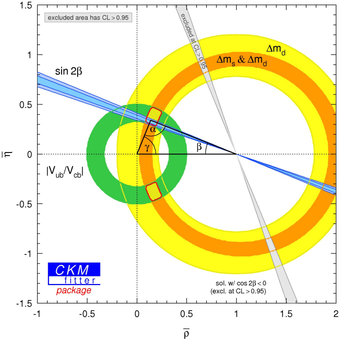
- Take SM $|\Delta B| = |\Delta S| = 1$ effective Hamiltonian
- Perform fit without NP, using isospin decomposition of hadronic amplitudes and order-of-magnitude estimates
- Include NP "operator-wise"
- Determine UT parameters independent of *this* NP
- Determine allowed ranges for NP contributions

Statistical treatment using RFit (CKMfitter)

UT analysis

Determine β and γ by independent measurements:

- Use only $|V_{ub}/V_{cb}|$, Δm_d and Δm_s (Moriond '09)



$$\sin 2\beta = 0.746^{+0.014}_{-0.020} \pm 0.081$$
$$\gamma = (65.7^{+1.8}_{-1.7} \pm 5.5)^\circ$$

- Tension decreased due to larger error for V_{ub}
- $B \to \tau\nu$ not included (avoid f_B/B_{B_d} discussion)
  Inclusion increases tension above the old level
  $\to$ large(r) $\Delta I = 0$ contributions

$B \to J/\psi K, \phi K$ in the SM

- $B \to J/\psi K$: Tree-dominated, governed by a single amplitude ($+\mathcal{O}(\frac{P}{T}\lambda^2) \sim \mathcal{O}(\lambda^3)$, "Gold-plated")
- $B \to \phi K$: Penguin-dominated, governed by a single amplitude ($+\mathcal{O}(\lambda^2)$)

➥ Expected observables (neglecting $\mathcal{O}(\lambda^3, \lambda^2)$ terms):

- Mixing-induced CP-Asymmetry:

$$S + \sin(2\beta) \simeq 0$$

- Direct CP-Asymmetries:

$$\Delta A_{CP} = A_{CP}^{dir}(\bar{B}^0) - A_{CP}^{dir}(B^-) \simeq 0$$

- Rate Asymmetry:

$$A_I = \frac{\Gamma_- - \Gamma_0}{\Gamma_- + \Gamma_0} \simeq 0$$

$B \to J/\psi K, \phi K$ - with New Physics

Experimental values for $B \to J/\psi K, \phi K$:

Observable	$B \to J/\psi K$	$B \to \phi K$
$S + \sin 2\beta$	$0.089^{+0.029}_{-0.032} \pm 0.081$	$0.31^{+0.18}_{-0.17} \pm 0.08$
ΔA_{CP}	$0.019 \pm 0.026(*)$	0.20 ± 0.16
A_I	0.036 ± 0.025	$-0.04^{+0.07}_{-0.08}$

➥ Deviation from SM expectations at $(1-2)\sigma$

Including NP operators:

- $S + \sin 2\beta$ constrains $b \to s\bar{c}c$ and $b \to s\bar{s}s$ contribution (but these induce no change in ΔA_{CP} and A_I)
- ΔA_{CP} and A_I constrain $b \to s\bar{u}u$ and $b \to s\bar{d}d$ (these result in a $\Delta I = 1$ contribution as well)

➥ Here: Show only fits to $\Delta I = 0 + 1$ contributions

Parameterisation

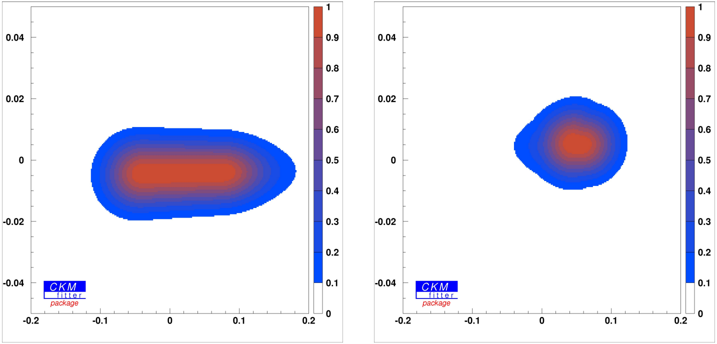
We parameterise the amplitudes in this case as

$$\begin{aligned}\mathcal{A}(B^+ \to J/\psi K^+) &= \mathcal{A}_0 \left[1 + r_0\, e^{i\theta_W} e^{i\phi_0} - r_1\, e^{i\theta_W} e^{i\phi_1}\right] \\ \mathcal{A}(\bar{B}_d \to J/\psi \bar{K}^0) &= \mathcal{A}_0 \left[1 + r_0\, e^{i\theta_W} e^{i\phi_0} + r_1\, e^{i\theta_W} e^{i\phi_1}\right]\end{aligned}$$

"Reparametrisation invariance":
Weak phase θ_W is not observable unless (some) parameters are fixed by theory ($\to B \to \pi K$)

Take $\theta_W = \pi - \gamma_{SM}$ as reference $\to$ Possible interpretation as (CKM suppressed) SM contributions

$b \to s\bar{u}u, \bar{d}d$ NP operator in $B \to J/\psi K$

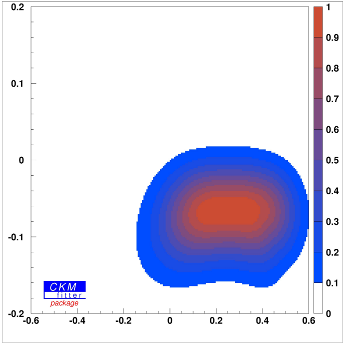


$r_0 \cos\phi_0^s vs. r_0 \sin\phi_0^s$ $r_1 \cos\phi_1^s vs. r_1 \sin\phi_1^s$

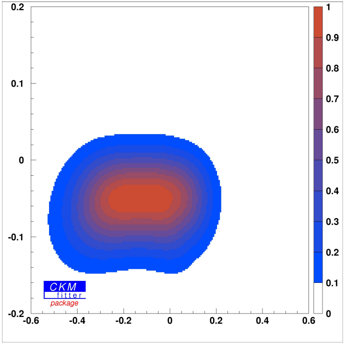
1σ-ranges:

$$r_0 \cos\phi_0 = [-0.074 \text{ to } 0.118], \quad r_0 \sin\phi_0 = [-0.015 \text{ to } 0.003],$$
$$r_1 \cos\phi_1 = [\ 0.014 \text{ to } 0.089], \quad r_1 \sin\phi_1 = [-0.002 \text{ to } 0.013].$$

$b \to s\bar{u}u, \bar{d}d$ NP operator in $B \to \phi K$



$r_0 \cos\phi_0^s vs. r_0 \sin\phi_0^s$



$r_1 \cos\phi_1^s vs. r_1 \sin\phi_1^s$

1σ-ranges:

$$r_0 \cos\phi_0 = [\ \ 0.03 \text{ to } 0.48] \,, \qquad r_0 \sin\phi_0 = [-0.11 \text{ to } -0.03] \,,$$
$$r_1 \cos\phi_1 = [-0.35 \text{ to } 0.10] \,, \qquad r_1 \sin\phi_1 = [-0.09 \text{ to } -0.01] \,.$$

Conclusion $B \to J/\psi K$ and $B \to \phi K$

- Assumed vanishing suppressed contributions from SM
  $\to$ confirmed in most estimates, see, however,
  [Ciuchini et al.'05, Faller et al.'08, talk by Th. Mannel]
- In both cases non-vanishing contributions from $\Delta I = 1$-operators preferred
- For $B \to \phi K$ also indication of $\Delta I = 0$ contribution
- Relative size as expected
- Small strong phases preferred

Future tasks:

- Belle/BaBar discrepancies in $A_{CP}(B \to J/\psi K)$
- Significant measurements of direct CP violation / critical observables
- Method to calculate matrix elements for these decays

$B \to \pi K$ in the SM

- Penguin dominant, but Tree and EW-Penguin contributions are relevant
- Parameterisation ($\mathcal{A}^{-0} = \mathcal{A}(B^- \to \pi^- \bar{K}^0)$ etc.):

$$\begin{aligned}
\mathcal{A}^{-0} &= P\left(1 + \epsilon_a\, e^{i\phi_a}\, e^{-i\gamma}\right) , \\
-\sqrt{2}\,\mathcal{A}^{0-} &= P\left(1 + \epsilon_a\, e^{i\phi_a}\, e^{-i\gamma} - \epsilon_{3/2}\, e^{i\phi_{3/2}}\left(e^{-i\gamma} - q e^{i\omega}\right)\right) , \\
-\mathcal{A}^{+-} &= P\left(1 + \epsilon_a\, e^{i\phi_a}\, e^{-i\gamma} - \epsilon_T\, e^{i\phi_T}\left(e^{-i\gamma} - q_C\, e^{i\omega_C}\right)\right) , \\
\sqrt{2}\,\mathcal{A}^{00} &= \mathcal{A}^{-0} + \sqrt{2}\,\mathcal{A}^{0-} - \mathcal{A}^{+-} .
\end{aligned}$$

- Too many parameters for a generic fit
- Additional theoretical input needed
  Statements involve stronger model-dependence

Inputs SM fit

We use the following results of QCDF for the SM fit:

- $SU(3)_F$ symmetry relation for $qe^{i\omega}$ receives only small corrections.
- ϵ_a is tiny (in accord with experiment).
- q_C is of minor numerical importance.

➥ we set $\epsilon_a \equiv 0$ and $q_{(C)}e^{i\omega_{(C)}}$ to their QCDF ranges, including "standard" power-corrections

$$\begin{aligned} q &= \quad 0.59 \pm 0.12 \pm 0.07\,, & \omega &= -0.044 \pm 0.049\,, \\ q_C &= 0.083 \pm 0.017 \pm 0.045\,, & \omega_C &= -1.05 \pm 0.86\,. \end{aligned}$$

➥ Not conservative at this point

$B \to \pi K$ SM results

Fitting for the remaining five quantities:

- Fit results in $\chi^2/\mathrm{d.o.f.} = 3.8/3$; not too bad
- Even $|C/T|$ is not large ("$B \to K\pi$ data compatible with SM" [Ciuchini et al. '08])
- Reason: $S + \sin 2\beta$ and A_{CP}^{00} shrinked
- But there are still some deviations:
  - $|\Delta\epsilon| := |\epsilon_T\, e^{i\phi_T} - \epsilon_{3/2}\, e^{i\phi_{3/2}}|$ still larger than in QCDF. Fit with $\Delta\epsilon \equiv 0$ does not work.
  - $\Delta A = A_{CP}^{0-} - A_{CP}^{+-} \approx C(\pi^0 K^0)$ not fulfilled ($1-2\sigma$, but: Belle/BaBar "annihilate")
    $\to$ Improvement with modified EWP only moderate [Baek et al. '09]
  - Using SU(3) with $B \to \pi^+\pi^0$ data leads to deviation in $S_{CP} - A_{CP}(\pi^0 K^0)$ plane [Fleischer et al. '08]

$B \to \pi K$ with NP

Including NP contributions:

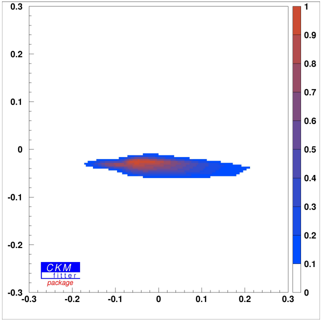
- Again, operators with $\Delta I = 0$ only do not help
- $b \to s\bar{d}d$ induces direct CP violation in $B^- \to \bar{K}^0\pi^-$
  $\to$ has to be small
- perform fit with $b \to s\bar{u}u$-operator
  $\to$ three new isospin amplitudes $\to r_0, r_{1/2}, r_{3/2}$

Again too many parameters $\to$ Additional approximations:

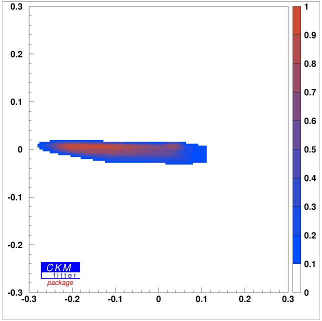
- Require $A_{CP}^{0-} \equiv 0 \to$ eliminates 2 parameters
- Set $\epsilon_T e^{i\phi_T} = \epsilon_{3/2} e^{i\phi_{3/2}} =$ (QCDF-ranges)
- $\theta_W = \pi - \gamma_{SM}$ as reference
  (but rep. inv. broken by QCDF-input)

Yields good fit ($\chi^2/\mathrm{d.o.f.} = 2.6/3$)
("Perfect" fit with huge NP contributions ignored)

$b \longrightarrow s\bar{u}u$ operator in $B \longrightarrow K\pi$



$r_{1/2} \cos \phi^s_{1/2}$ *vs.* $r_{1/2} \sin \phi^s_{1/2}$



$r_{3/2} \cos \phi^s_{3/2}$ *vs.* $r_{3/2} \sin \phi^s_{3/2}$

$r_{1/2} \cos \phi^s_{1/2}$	$r_{1/2} \sin \phi^s_{1/2}$	$r_{3/2} \cos \phi^s_{3/2}$	$r_{3/2} \sin \phi^s_{3/2}$
$[-0.12; 0.05]$	$[-0.05; -0.02]$	$[-0.24; 0.05]$	$[-0.01; 0.01]$

- Solution shown: reasonable order of magnitude
- Again $b \longrightarrow s\bar{u}u$ preferred
- Small strong phases

Conclusion and outlook

- Tensions in $b \to s\bar{s}s$ and V_{ub} reduced with recent data
- Not discussed: $B \to \tau\nu$, $B_{d,s}$-mixing, ϵ_K, ...
- Still curious pattern: (NP?) $b \to s\bar{u}u$ operator could explain the data
- $B \to \pi K$: Room for NP, QCD difficult to discriminate
  Conflict with $B \to \pi\pi$ on which side?
- ➥ Moderate improvement of experimental sensitivity may lead to interesting conclusions...

Precision measurements in B-decays continue to give interesting constraints on NP flavour structure ($\to$ LHCb, Super-B,...)

Backupslides

- Experimental data
- Which input to use?
- Reparametrisation invariance
- Powercounting in $B \longrightarrow J/\psi K, \phi K$

Experimental data for $b \to s\bar{q}q$ transitions

Decay	BR	A_{CP}	S_{CP}
$B^- \to J/\psi K^-$	$(10.07 \pm 0.35)10^{-4}$	$0.017 \pm 0.016(*)$	–
$\bar{B}^0 \to J/\psi \bar{K}^0$	$(\ 8.71 \pm 0.32)10^{-4}$	$-0.002 \pm 0.020(*)$	0.657 ± 0.025
$B^- \to \phi K^-$	$(8.3 \pm 0.65)10^{-6}$	0.034 ± 0.044	–
$\bar{B}^0 \to \phi \bar{K}^0$	$(8.3^{+1.2}_{-1.0})10^{-6}$	0.23 ± 0.15	$-(0.44^{+0.17}_{-0.18})$
$B^- \to \pi^0 K^-$	$(12.9 \pm 0.6)10^{-6}$	0.050 ± 0.025	–
$B^- \to \pi^- \bar{K}^0$	$(23.1 \pm 1.0)10^{-6}$	0.009 ± 0.025	–
$\bar{B}^0 \to \pi^+ K^-$	$(19.4 \pm 0.6)10^{-6}$	$-0.098^{+0.012}_{-0.011}$	–
$\bar{B}^0 \to \pi^0 \bar{K}^0$	$(\ 9.8 \pm 0.6)10^{-6}$	-0.01 ± 0.10	-0.57 ± 0.17

Which input to use?

Recent analyses of $B \to \pi K$ puzzle come to different conclusions. Schematically:

- No NP needed in $B \to \pi K$ [Ciuchini et al. '08]
- Puzzle reduced, mod. EWP do not help much [Baek et al. '09]
- Discrepancy in $S_{CP} - A_{CP}(B \to \pi^0 K^0)$ plane, mod. EWP help [Fleischer et al. '08]

Inputs are:

- QCDF + large non-factorizable corrections
- Fleischer/Neubert/Rosner relations (both)
- Neubert/Rosner relation I, $BR(B \to \pi^+\pi^0)$ (fixes mainly $\epsilon_{3/2}$, large phase)

Reparametrisation invariance

The amplitude is invariant under the transformations

$$\begin{aligned}
\mathcal{A}_0 &\to \mathcal{A}_0\,(1+\xi\, r_0\, e^{i\phi_s^0})\,,\\
r_0\, e^{i\phi_s^0} &\to \frac{r_0\, e^{i\phi_s^0}\sqrt{1-2\,\xi\,\cos\phi_w^0+\xi^2}}{1+\xi\, r_0\, e^{i\phi_s^0}}\\
e^{i\phi_w^0} &\to \sqrt{\frac{e^{i\phi_w^0}-\xi}{e^{-i\phi_w^0}-\xi}}\,,\\
r_1\, e^{i\phi_s^1} &\to \frac{r_1\, e^{i\phi_s^1}}{1+\xi\, r_0\, e^{i\phi_s^0}}\,,
\end{aligned}$$

as long as the leading SM-matrix-element $\mathcal{A}_0$ is not fixed.

$B \to J/\psi K$

SM and NP contributions and suppression factors:

Contr.	**Suppression factors** Op.	Dyn.	CKM	NP	Π	**Comment**
$\lambda_c^s T$	1	1	1	-	$\mathbf{1}$	$\mathcal{O}(1) \longrightarrow \lambda_c^s A_c^0$
$\lambda_c^s P^{\bar{c}c}$	λ	1	1	-	$\boldsymbol{\lambda}$	
$\lambda_c^s P^{\bar{q}q}_{I=0}$	λ	λ	1	-	$\boldsymbol{\lambda}^2$	
$\lambda_c^s P^{\bar{q}q}_{I=1}$	λ^2	λ	1	-	$\boldsymbol{\lambda}^3$	
$\lambda_u^s T$	1	λ	λ^2	-	$\boldsymbol{\lambda}^3$	$\leq \mathcal{O}(\lambda^3) \times \lambda_c^s A_c^0$ $\longrightarrow$ "gold-plated mode"
$\lambda_u^s P^{\bar{c}c}$	λ	1	λ^2	-	$\boldsymbol{\lambda}^3$	
$\lambda_u^s P^{\bar{q}q}_{I=0}$	λ	λ	λ^2	-	$\boldsymbol{\lambda}^4$	
$\lambda_u^s P^{\bar{q}q}_{I=1}$	λ^2	λ	λ^2	-	$\boldsymbol{\lambda}^5$	
$P^{\bar{c}c}_{0/c}$	1	1	1	λ	$\boldsymbol{\lambda}$	$\mathcal{O}(\lambda) \times \lambda_c^s A_c^0$
$P^{\bar{q}q}_{0/c,I=0}$	1	λ	1	λ	$\boldsymbol{\lambda}^2$	
$P^{\bar{q}q}_{c,I=1}$	1	λ	1	λ	$\boldsymbol{\lambda}^2$	$\mathcal{O}(\lambda^2) \times \lambda_c^s A_c^0$

$B \to \phi K$

SM and NP contributions and suppression factors:

Contr.	Suppression factors					Comment
	Op.	Dyn.	CKM	NP	Π	
$\lambda_c^s T$	1	λ	1	-	$\boldsymbol{\lambda}$	$\mathcal{O}(\lambda) \longrightarrow \lambda_c^s A_c^0$
$\lambda_c^s P^{\bar{s}s}$	λ	1	1	-	$\boldsymbol{\lambda}$	
$\lambda_c^s P^{\bar{q}q}_{I=0}$	λ	λ	1	-	$\boldsymbol{\lambda}^2$	
$\lambda_c^s P^{\bar{q}q}_{I=1}$	λ^2	λ	1	-	$\boldsymbol{\lambda}^3$	$\leq \mathcal{O}(\lambda^2) \times \lambda_c^s A_c^0$
$\lambda_u^s T$	1	λ	λ^2	-	$\boldsymbol{\lambda}^3$	
$\lambda_u^s P^{\bar{s}s}$	λ	1	λ^2	-	$\boldsymbol{\lambda}^3$	
$\lambda_u^s P^{\bar{q}q}_{I=0}$	λ	λ	λ^2	-	$\boldsymbol{\lambda}^4$	
$\lambda_u^s P^{\bar{q}q}_{I=1}$	λ^2	λ	λ^2	-	$\boldsymbol{\lambda}^5$	
$P^{\bar{s}s}_{0/c}$	1	1	1	λ	$\boldsymbol{\lambda}$	$\mathcal{O}(1) \times \lambda_c^s A_c^0$
$P^{\bar{q}q}_{0/c,I=0}$	1	λ	1	λ	$\boldsymbol{\lambda}^2$	
$P^{\bar{q}q}_{c,I=1}$	1	λ	1	λ	$\boldsymbol{\lambda}^2$	$\mathcal{O}(\lambda) \times \lambda_c^s A_c^0$