Determining CP violation angle γ with B decays into a scalar/tensor meson

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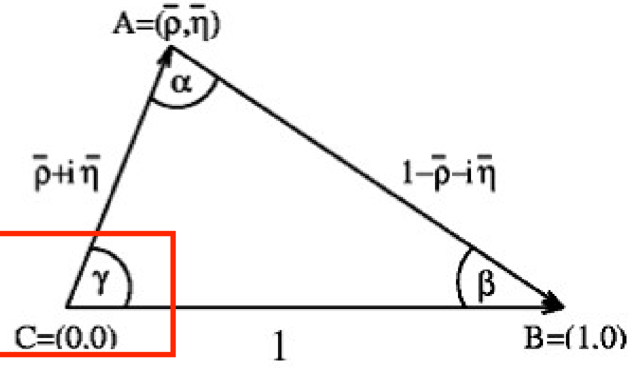
CKM angle γ/ϕ_3

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ \lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

Wolfenstein parameterization

$\lambda \sim 0.22$	$A \sim 0.8$
$\rho \sim 0.16$	$\eta \sim 0.34$

$$\gamma = \arg\left(-\frac{V_{ud}V^*_{ub}}{V_{cd}V^*_{cb}} \right)$$



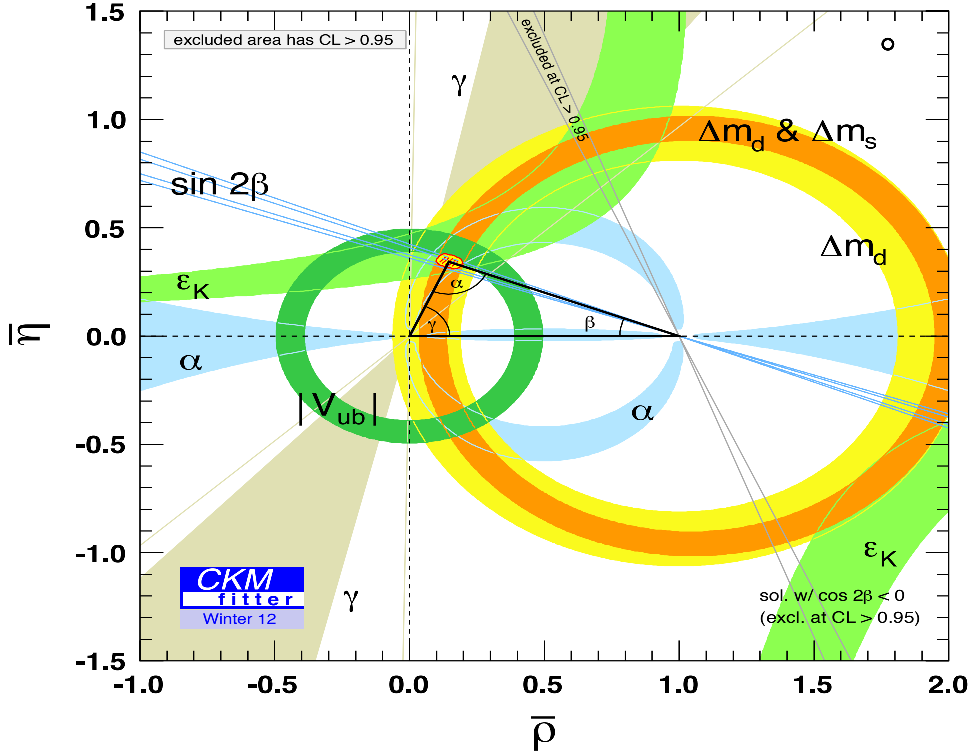
Motivation and importance of measuring γ

Determination of γ is important because (together with V_{ub} contraint) it selects ρ−η value valid in most of the NP extensions:

$$\alpha+\beta+\gamma=180°$$

γ is still the less precisely known CKM angle

$$\gamma = (66 \pm 12)°$$



Experiments providing most of analyses today

BELLE

3.1 GeV e^+
9 GeV e^-

3.5 GeV e^+
8 GeV e^-

Experiments that start collecting results recently

LHCb

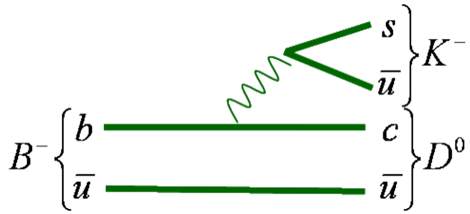
Planned facilities

SuperB

Belle II

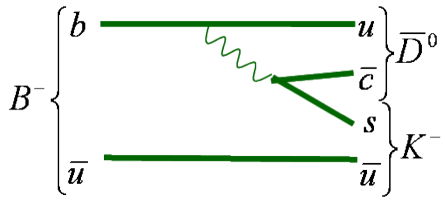
γ measurements from $B \rightarrow DK$

b→c (V_{cb}, real): favored



Advantages:
- Only tree decays.
- Largely unaffected by New Physics scenarios
- No hadronic uncertainties

b→u (V_{ub}, = $|V_{ub}| e^{-i\gamma}$):suppressed



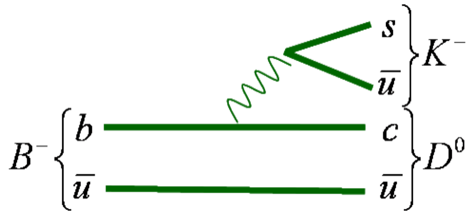
D CP eigenstate :

$K^+K^-/\pi^+\pi^-$

$$\sqrt{2}A(B^+ \to D^0_\pm K^+) = A(B^+ \to D^0 K^+) \pm A(B^+ \to \bar{D}^0 K^+),$$
$$\sqrt{2}A(B^- \to D^0_\pm K^-) = A(B^- \to D^0 K^-) \pm A(B^- \to \bar{D}^0 K^-).$$

γ measurements from $B \to DK$

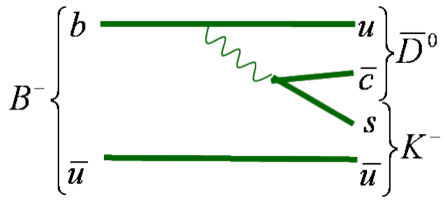
b→c ($V_{cb,}$ real): favored



$\approx V_{cb} V^*_{us} \times a_1 \times f_K \times F^{B \to D}$

factorization

b→u ($V_{ub,}$ = $|V_{ub}| e^{-i\gamma}$): suppressed



$\approx V_{ub} V^*_{cs} \times a_2 \times f_D \times F^{B \to K}$

$$r_B^{K_J} \equiv \left| A(B^- \to \bar{D}^0 K_J^-)/A(B^- \to D^0 K_J^-) \right|,$$
$$\delta_B^{K_J} \equiv arg\left[e^{i\gamma} A(B^- \to \bar{D}^0 K_J^-)/A(B^- \to D^0 K_J^-) \right],$$

$$r_B^K = 0.107 \pm 0.010, \quad \delta_B^K = (112^{+12}_{-13})^\circ$$

$$\begin{aligned} R^K_{CP\pm} &= 2\frac{\mathcal{B}(B^- \to D_{CP\pm}K^-) + \mathcal{B}(B^+ \to D_{CP\pm}K^+)}{\mathcal{B}(B^- \to D^0 K^-) + \mathcal{B}(B^+ \to \bar{D}^0 K^+)} \\ &= 1 + (r_B^K)^2 \pm 2 r_B^K \cos\delta_B^K \cos\gamma, \\ A^K_{CP\pm} &= \frac{\mathcal{B}(B^- \to D_{CP\pm}K^-) - \mathcal{B}(B^+ \to D_{CP\pm}K^+)}{\mathcal{B}(B^- \to D_{CP\pm}K^-) + \mathcal{B}(B^+ \to D_{CP\pm}K^+)} \\ &= \pm 2 r_B^K \sin\delta_B^K \sin\gamma / R^K_{CP\pm}, \end{aligned}$$

CP eigenstate

- K^+K^-, $\pi^+\pi^-$

DCS D-decay mode

- $K^+\pi^-$, $K^+\pi^-\pi^+\pi^-$, $K^+\pi^-\pi^0$

SCS multi-body state

- $K_S\,\pi^+\pi^-$, $K_S\,K^+K^-$, $K^+K^-\pi^+\pi^-$

$B^- \to DK^-$ $\quad D \to K^+K^-, \pi^+\pi^-$

(favoured ⊕ suppressed) ⊗ *CP* eigenstates

"*CP*" or "GLW" modes

M. Gronau and D. London, *How to determine all the angles of the unitarity triangle from $B_d^0 \to DK_s^0$ and $B_s^0 \to D\phi$*, Phys. Lett. **B253** (1991) 483; M. Gronau and D. Wyler, *On determining a weak phase from CP asymmetries in charged B decays*, Phys. Lett. **B265** (1991)

$B^- \to DK^-$ $\quad D \to \pi^-K^+$

(favoured ⊕ suppressed) ⊗ (suppressed ⊕ favoured)

"ADS" mode

D. Atwood, I. Dunietz, and A. Soni, *Enhanced CP violation with $B \to KD^0(\bar{D}^0)$ modes and extraction of the CKM angle γ*, Phys.Rev.Lett. **78** (1997) 3257, arXiv:hep-ph/9612433;

what if we consider a different Kaon resonance?

K_0^* and K_2^*

l	s	J	$^{2s+1}L_J$	J^{PC}	Meson
$l=0$	$s=0$	$J=0$	$^1S_0$	0^{-+}	Pseudoscalar (P)
	$s=1$	$J=1$	$^3S_1$	1^{--}	Vector (V)
$l=1$	$s=0$	$J=1$	$^1P_1$	1^{+-}	Axial-vector $(A(^1P_1))$
	$s=1$	$J=0$	$^3P_0$	0^{++}	Scalar (S)
		$J=1$	$^3P_1$	1^{++}	Axial-vector $(A(^3P_1))$
		$J=2$	$^3P_2$	2^{++}	Tensor (T)

$K_0^*(1430)$ [mm] $I(J^P) = \frac{1}{2}(0^+)$

$K_2^*(1430)$ $I(J^P) = \frac{1}{2}(2^+)$

K_0^*: small decay constants

$$\langle K_0^{*-}(1430)|\bar{s}\gamma^\mu u|0\rangle = f_{K_0^*} p^\mu_{K_0^*},$$

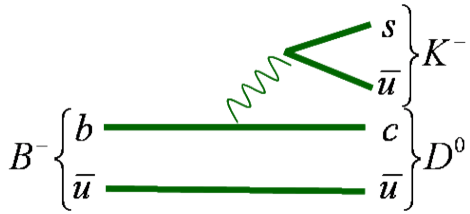
The current experimental data on $\tau \to K_0^{*-}(1430)\bar{\nu}_\tau$ places an upper bound

$$|f_{K_0^*}| < 107\text{MeV},$$

which is not very stringent. Adopting an estimate based on QCD sum rules

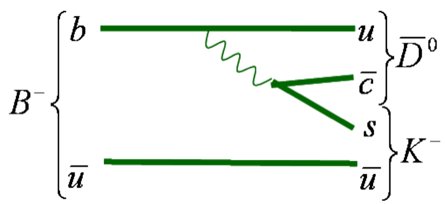
$$f_{K_0^*} = -24\text{MeV}, \quad \text{or} \quad f_{K_0^*} = 36\text{MeV},$$

b→c ($V_{cb,}$ real): favored



$$\approx V_{cb} V^*_{us} \times a_1 \times f_{K^*0} \times F^{B \to D}$$

b→u ($V_{ub,}$ = $|V_{ub}|\, e^{-i\gamma}$): suppressed



$$\approx V_{ub} V^*_{cs} \times a_2 \times f_D \times F^{B \to K^*0}$$

K_0^*: small decay constants

$$\langle K_0^{*-}(1430)|\bar{s}\gamma^\mu u|0\rangle = f_{K_0^*} p^\mu_{K_0^*},$$

The current experimental data on $\tau \to K_0^{*-}(1430)\bar{\nu}_\tau$ places an upper bound

$$|f_{K_0^*}| < 107\text{MeV},$$

which is not very stringent. Adopting an estimate based on QCD sum rules

$$f_{K_0^*} = -24\text{MeV}, \quad \text{or} \quad f_{K_0^*} = 36\text{MeV},$$

Using one set of results for the $B \to K_0^*$ form factors calculated in the perturbative QCD approach(corresponding to $f_{K_0^*} = 36$ MeV), the $B \to D$ form factors from light-front quark model and $a_2 = 0.2, a_1 = 1$ we estimate $C/T \sim 1.2$ and

$$r_B^{K_0^*} = |CV_{ub}V_{cs}^*/[V_{cb}V_{us}^*(C-T)]| \sim 2.$$

Reversing the sign of a_2, we obtain a smaller $r_B^{K_0^*} \simeq 0.3$, which is still larger than r_B^K.

$$r_B^{K_J} \equiv \left|A(B^- \to \bar{D}^0 K_J^-)/A(B^- \to D^0 K_J^-)\right| ,$$

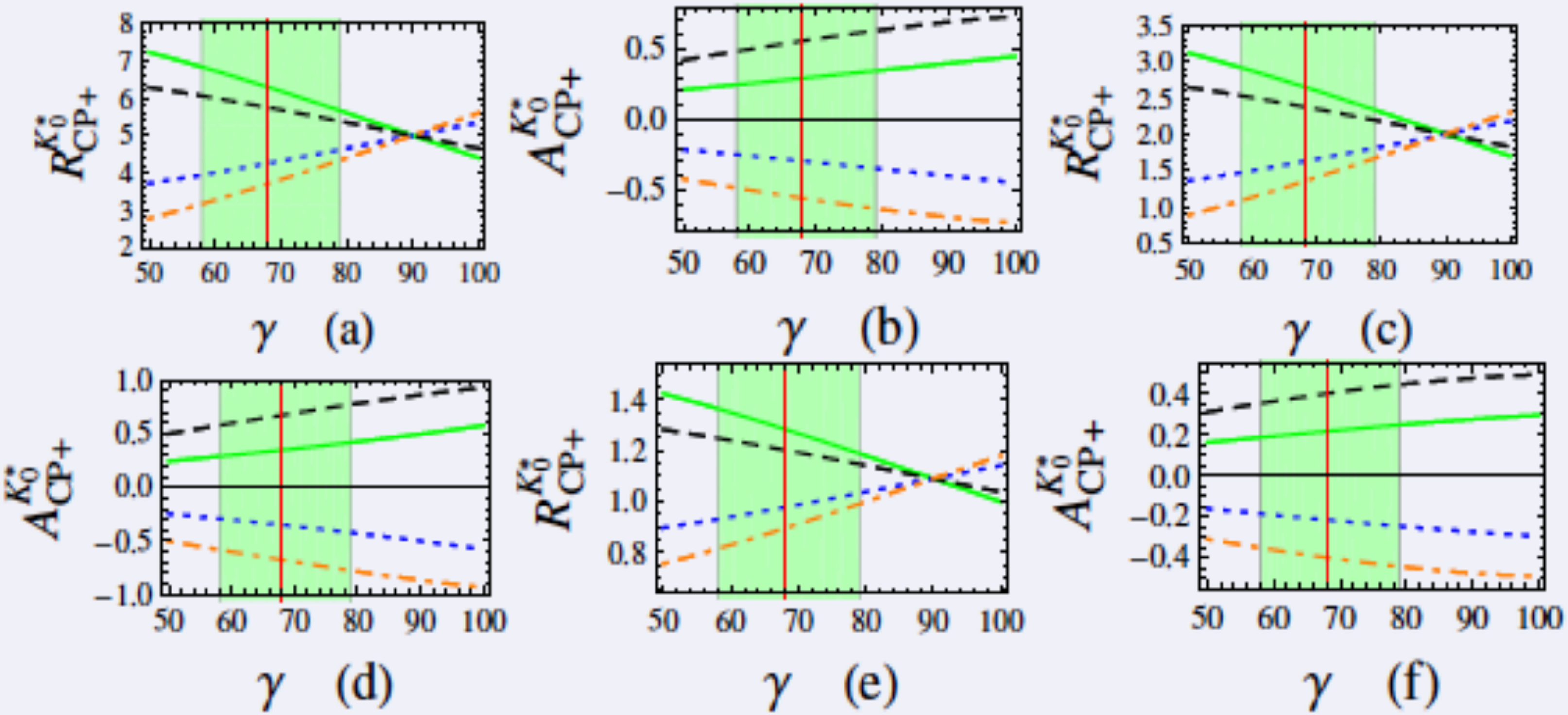
$$\delta_B^{K_J} \equiv arg\left[e^{i\gamma} A(B^- \to \bar{D}^0 K_J^-)/A(B^- \to D^0 K_J^-)\right] ,$$

$$\begin{aligned}
R^K_{CP\pm} &= 2\frac{\mathcal{B}(B^- \to D_{CP\pm}K^-) + \mathcal{B}(B^+ \to D_{CP\pm}K^+)}{\mathcal{B}(B^- \to D^0 K^-) + \mathcal{B}(B^+ \to \bar{D}^0 K^+)} \\
&= 1 + (r_B^K)^2 \pm 2 r_B^K \cos\delta_B^K \cos\gamma, \\
A^K_{CP\pm} &= \frac{\mathcal{B}(B^- \to D_{CP\pm}K^-) - \mathcal{B}(B^+ \to D_{CP\pm}K^+)}{\mathcal{B}(B^- \to D_{CP\pm}K^-) + \mathcal{B}(B^+ \to D_{CP\pm}K^+)} \\
&= \pm 2 r_B^K \sin\delta_B^K \sin\gamma / R^K_{CP\pm},
\end{aligned}$$

better sensitivities to gamma!

Large CP asymmetries

dependence of $R_{CP+}^{K_0^*}$ and $A_{CP+}^{K_0^*}$ on γ



In panels (a,b), $r_B^{K_0^*} = 2$ is employed, in panels (c,d) $r_B^{K_0^*} = 1$ and in panels (e,f) $r_B^{K_0^*} = 0.3$. The solid (green), dashed (black), dotted (blue) and dot-dashed (orange) lines in diagrams (a,c,e) correspond to $\delta_B^{K_0^*} = (30, 60, 120, 150)°$ respectively, while the corresponding lines in diagrams (b,d,f) correspond to $\delta_B^{K_0^*} = (30, 60, -30, -60)°$. The shadowed (light-green) region denotes the current bounds on $\gamma = (68^{+10}_{-11})°$ from a combined analysis of $B^\pm \to DK^\pm$, in which the vertical (red) line corresponds to the central value.

B->DK$_2$*

Turning to the $B^{\pm} \to DK_2^{*\pm}$ mode in which the matrix element of the vector and the axial-vector current between the QCD vacuum and the K_2^* state is zero, we find a vanishing color-allowed amplitude T. Accordingly, the ratio $r_B^{K_2^*}$ is from the product of CKM matrix elements:

$$r_B^{K_2^*} = 0.5.$$

An estimate of the branching ratios can be made by using the data on the $B \to J/\psi K_2^*$

$$\frac{\mathcal{B}(B^- \to D^0 K_2^{*-})}{\mathcal{B}(B \to J/\psi K_2^{*0})} \simeq x_{K_2^*} \left| \frac{V_{cb} V_{us}^*}{V_{cb} V_{cs}^*} \frac{f_D}{f_{J/\psi}} \right|^2 \sim 0.8\%,$$

with $x_{K_2^*}$ being the ratio of the form factor products which is evaluated from a recent calculation of $B \to K_2^*$ form factor in the PQCD approach: $x_{K_2^*} \simeq 0.5$. The branching ratio $\mathcal{B}(B \to J/\psi K_2^{*0}) = (4.0 \pm 2.4) \times 10^{-4}$ extracted from the data on $B^- \to J/\psi K^- \pi^+ \pi^-$ gives

$$\mathcal{B}(B^- \to D^0 K_2^{*-}) \simeq 3 \times 10^{-6}.$$

$B \to DK_2^*$

PQCD estimate (in units of 10^{-6}) by Z.T. Zou,X.Yu and C.D.Lu (1205.2971)

Decay Modes	Class	This Work	SDV[14]	KLO[15]
$B^- \to \bar{D}^0 K_2^{*-}$	C	3.7±1.7	1.3	1.2
$B^- \to D^0 K_2^{*-}$	T	33±16	8.7	7.3

[14] Sharma Dhir, Verma, Phys. Rev.D 83, 014007 (2011)
[15] Kim, Lim S. Oh, Phys. Rev. D 67, 014011 (2003).

QCD corrections enhanced the branching ratios of $B^- \to D^0 K_2^{*-}$

K_0^* and K_2^* Decay

The $K^*_{0,2}$ have significant decay rates into $K\pi$, with $\mathcal{B}(K_0^* \to K\pi) = (93 \pm 10)\%$ and $\mathcal{B}(K_2^* \to K\pi) = (49.9 \pm 1.2)\%$, and the final mesons are also easy to detect in experiments at hadron colliders.

Since the CKM matrix elements for the K_0^* and K_2^* are the same, no knowledge of the resonance structure in this method is required and therefore the angle γ can be extracted without any hadronic uncertainty.

Compared with the BR of $B^- \to \bar{D}^0 K^-$, of order 10^{-6}, which is an unavoidable entry in the currently-adopted methods to determine γ, the summed BRs for the channels involving K_0^* and K_2^*, of order 10^{-5}, are comparable or even larger, and hence their measurements will not be statistically limited. The large amount of data accumulated by LHCb recently and in future will lead to a promising prospect of the proposed method.

$K_0^*(1430)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\pi$	(93 ± 10) %	619

$K_2^*(1430)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$K\pi$	(49.9 ± 1.2) %		619

Conclusion

γ is the less precisely known CKM angle.

I proposed that B→DK*$_{0,2}$ can be used to extract γ

- Color-allowed and color-suppressed amplitudes are comparable
- Large CP asymmetries are expected in these processes
- Branching ratios are of the order 10^{-6} or may be even larger.

I also hope that this proposal can be fleshed out as part of, say, a graduate student Masters project with some experimental group.

Thank you for your attention!