Determination of γ and $-2\beta_s$ from charmless two-body decays of beauty mesons

V. Vagnoni
(INFN Bologna)

Implications of LHCb measurements and future prospects

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Introduction

- Long-awaited result in LHCb
  - LHCb reoptimization TDR
    - First seminal "γ from B$\rightarrow$hh" analysis
  - "γ from loops" working group
    - The aim was in the name
  - Roadmap document (arXiv:0912.4179)
    - Similar analysis in conclusive part of Chap. 3
- Analysis refined through the years
- **Paper submitted recently**
  - **arXiv:1408.4368**

Theoretical formalism

- The time-dependent CP asymmetry of a $B_{(s)}$ meson decaying into a self-conjugated final state, $f = \{\pi^+\pi^-, \pi^0\pi^0, K^+K^-\}$, can be written as

$$\mathcal{A}(t) = \frac{\Gamma_{\bar{B}^0_{(s)}\to f}(t) - \Gamma_{B^0_{(s)}\to f}(t)}{\Gamma_{\bar{B}^0_{(s)}\to f}(t) + \Gamma_{B^0_{(s)}\to f}(t)} = \frac{-C_f \cos\left(\Delta m_{d(s)} t\right) + S_f \sin\left(\Delta m_{d(s)} t\right)}{\cosh\left(\frac{\Delta\Gamma_{d(s)}}{2} t\right) + A_f^{\Delta\Gamma} \sinh\left(\frac{\Delta\Gamma_{d(s)}}{2} t\right)}$$

$$C_f = \frac{1 - |\lambda_f|^2}{1 + |\lambda_f|^2}, \qquad S_f = \frac{2\mathrm{Im}\lambda_f}{1 + |\lambda_f|^2}, \qquad A_f^{\Delta\Gamma} = -\frac{2\mathrm{Re}\lambda_f}{1 + |\lambda_f|^2},$$

$$(C_f)^2 + (S_f)^2 + \left(A_f^{\Delta\Gamma}\right)^2 = 1 \qquad\qquad \lambda_f = \frac{q}{p}\frac{\bar{A}_f}{A_f}.$$

Two independent parameters (C_f and S_f) and a sign (of $A_f^{\Delta\Gamma}$)

Theoretical formalism

- The CP-averaged branching ratio of a $B_{(s)}$ meson decaying into a self-conjugated final state, $f = \{\pi^+\pi^-, \pi^0\pi^0, K^+K^-\}$, is

$$\mathcal{B}_f = \frac{1}{2} F(B^0_{(s)} \to f) \left(|\bar{A}_f|^2 + |A_f|^2 \right)$$

$$F(B^0 \to \pi^+\pi^-) = \frac{\sqrt{m^2_{B^0} - 4m^2_{\pi^+}}}{m^2_{B^0}} \tau_{B^0},$$

$$F(B^0 \to \pi^0\pi^0) = \frac{\sqrt{m^2_{B^0} - 4m^2_{\pi^0}}}{m^2_{B^0}} \tau_{B^0},$$

$B_s \to K^+K^-$ effective lifetime

$$F(B^0_s \to K^+K^-) = \frac{\sqrt{m^2_{B^0_s} - 4m^2_{K^+}}}{m^2_{B^0_s}} \left[2\tau_{B^0_s} - (1 - y_s^2)\, \tau(B^0_s \to K^+K^-) \right] \qquad y_s = \Delta\Gamma_s/(2\Gamma_s)$$

Last equation applies a correction for the nonzero width difference of B_s mass eigenstates **[PRD 86 (2012) 014027]**

Theoretical formalism

- In the case of $B^{\pm}$ decaying to $f = \pi^{\pm}\pi^{0}$, the direct CP asymmetry is

$$\mathcal{A}_f = \frac{|\bar{A}_{\bar{f}}|^2 - |A_f|^2}{|\bar{A}_{\bar{f}}|^2 + |A_f|^2},$$

A_f = amplitude of $B^+ \rightarrow \pi^+\pi^0$
$\bar{A}_{\bar{f}}$ = amplitude of $B^- \rightarrow \pi^-\pi^0$

- The CP-averaged branching ratio of $B^{\pm} \rightarrow \pi^{\pm}\pi^{0}$ is

$$\mathcal{B}_f = \frac{1}{2} F(B^+ \to f) \left(|\bar{A}_{\bar{f}}|^2 + |A_f|^2 \right)$$

$$F(B^+ \to \pi^+\pi^0) = \frac{\sqrt{m_{B^+}^2 - (m_{\pi^+} + m_{\pi^0})^2}}{m_{B^+}^2} \tau_{B^+}$$

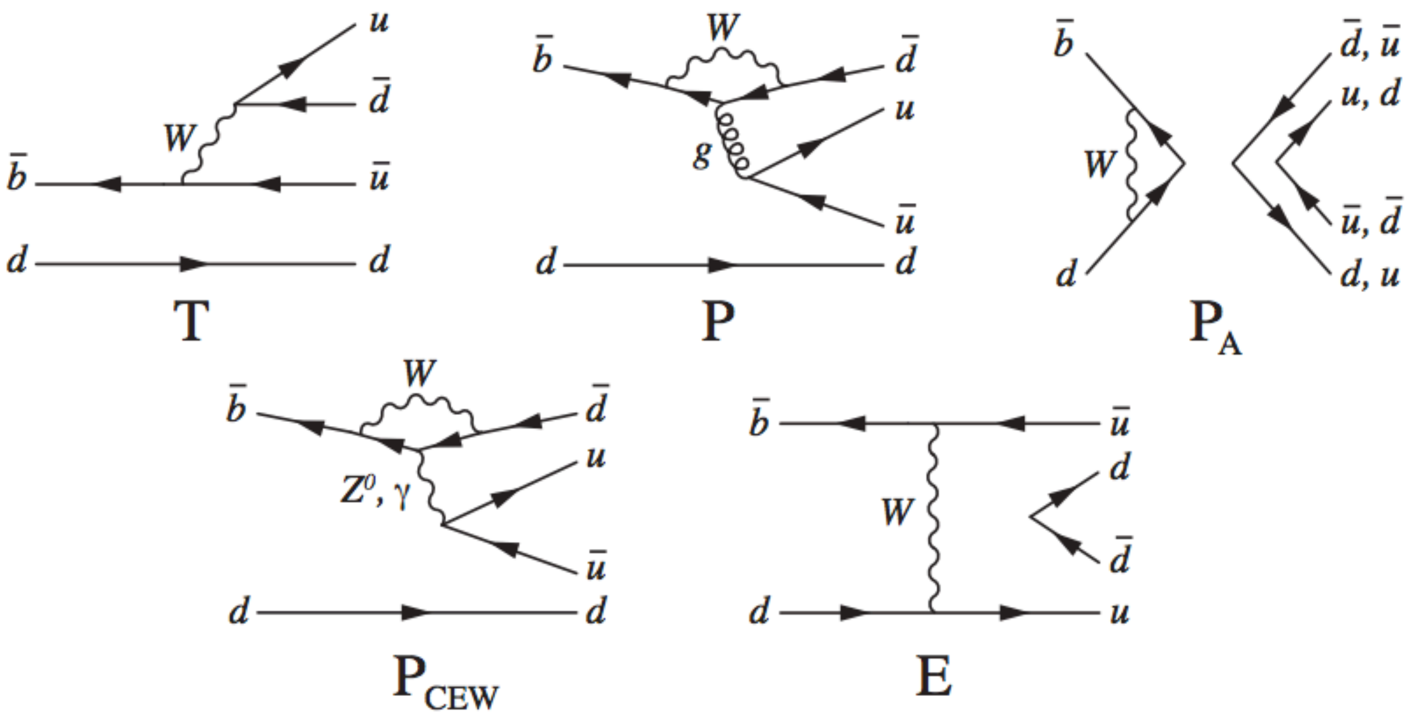
Experimental status

Quantity	BaBar	Belle	CDF	LHCb
$C_{\pi^+\pi^-}$	$-0.25 \pm 0.08 \pm 0.02$	$-0.33 \pm 0.06 \pm 0.03$	–	$-0.38 \pm 0.15 \pm 0.02$
$S_{\pi^+\pi^-}$	$-0.68 \pm 0.10 \pm 0.03$	$-0.64 \pm 0.08 \pm 0.03$	–	$-0.71 \pm 0.13 \pm 0.02$
$\rho(C_{\pi^+\pi^-}, S_{\pi^+\pi^-})$	-0.06	-0.10	–	0.38
$\mathcal{B}_{\pi^+\pi^-} \times 10^6$	$5.5 \pm 0.4 \pm 0.3$	$5.04 \pm 0.21 \pm 0.18$	$5.02 \pm 0.33 \pm 0.35$	$5.08 \pm 0.17 \pm 0.37$
$C_{K^+K^-}$	–	–	–	$0.14 \pm 0.11 \pm 0.03$
$S_{K^+K^-}$	–	–	–	$0.30 \pm 0.12 \pm 0.04$
$\rho(C_{K^+K^-}, S_{K^+K^-})$	–	–	–	0.02
$\mathcal{B}_{K^+K^-} \times 10^6$	–	$38^{+10}_{-9} \pm 7$	$25.8 \pm 2.2 \pm 1.7$	$23.0 \pm 0.7 \pm 2.3$
$\mathcal{A}_{\pi^+\pi^0}$	$-0.03 \pm 0.08 \pm 0.01$	$-0.025 \pm 0.043 \pm 0.007$	–	–
$\mathcal{B}_{\pi^+\pi^0} \times 10^6$	$5.02 \pm 0.46 \pm 0.29$	$5.86 \pm 0.26 \pm 0.38$	–	–
$C_{\pi^0\pi^0}$	$-0.43 \pm 0.26 \pm 0.05$	$0.44^{+0.53}_{-0.52} \pm 0.17$	–	–
$\mathcal{B}_{\pi^0\pi^0} \times 10^6$	$1.83 \pm 0.21 \pm 0.13$	$2.3^{+0.4+0.2}_{-0.5-0.3}$	–	–

- LHCb results are published in
  - JHEP 10 (2012) 037 (Branching ratios)
  - JHEP 10 (2013) 183 (CP asymmetries)

Note: new Belle result on BR($B \to \pi^0\pi^0$) not included

$B^0 \rightarrow \pi^+\pi^-$ decay amplitude

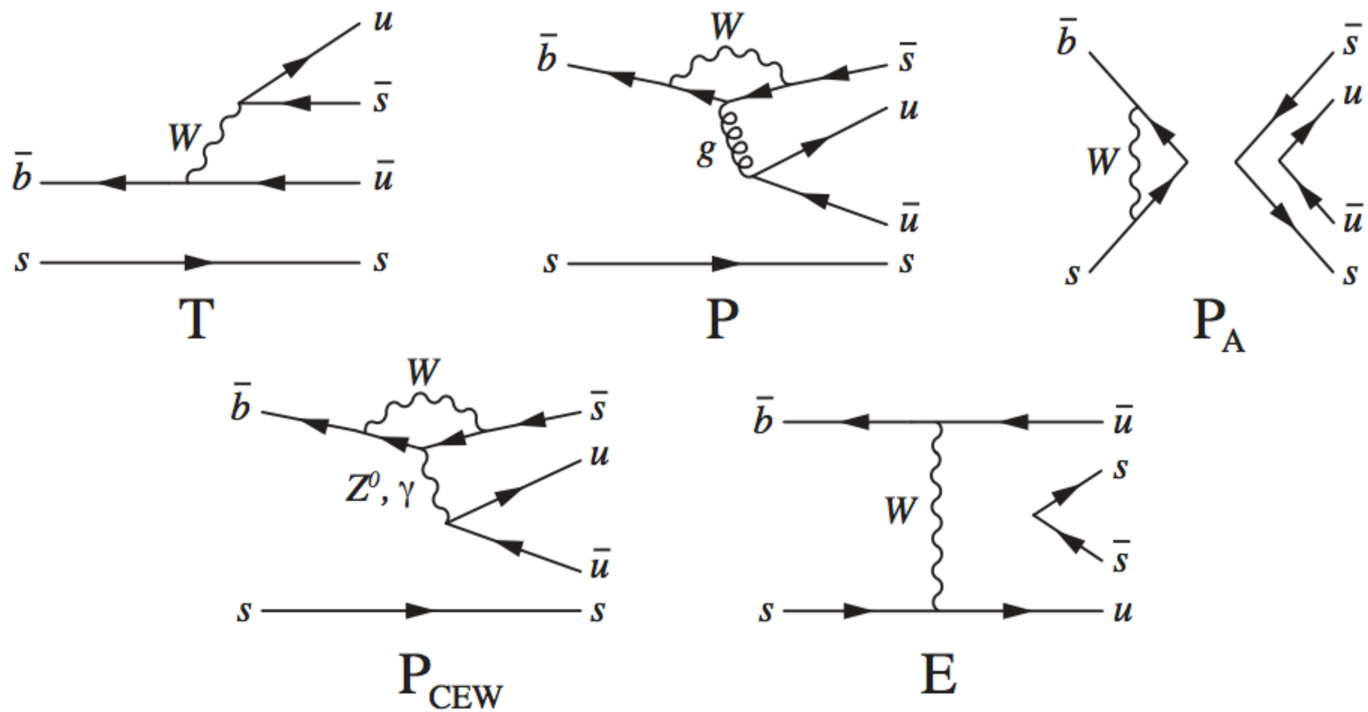


$$A_{\pi^+\pi^-} = D\left(e^{i\gamma} - de^{i\vartheta}\right) \qquad \bar{A}_{\pi^+\pi^-} = D\left(e^{-i\gamma} - de^{i\vartheta}\right)$$

$$D = A\lambda^3 R_b \left(-\mathrm{T} - \mathrm{P}^u - c_u \mathrm{P}^u_{\mathrm{CEW}} - \mathrm{P}^u_{\mathrm{A}} + \mathrm{P}^t + c_u \mathrm{P}^t_{\mathrm{CEW}} + \mathrm{P}^t_{\mathrm{A}} - \mathrm{E}\right)$$

$$G = A\lambda^3 \left(-\mathrm{P}^c - c_u \mathrm{P}^c_{\mathrm{CEW}} - \mathrm{P}^c_{\mathrm{A}} + \mathrm{P}^t + c_u \mathrm{P}^t_{\mathrm{CEW}} + \mathrm{P}^t_{\mathrm{A}}\right) \qquad de^{i\vartheta} = \frac{G}{D}$$

$B_s \rightarrow K^+K^-$ decay amplitude



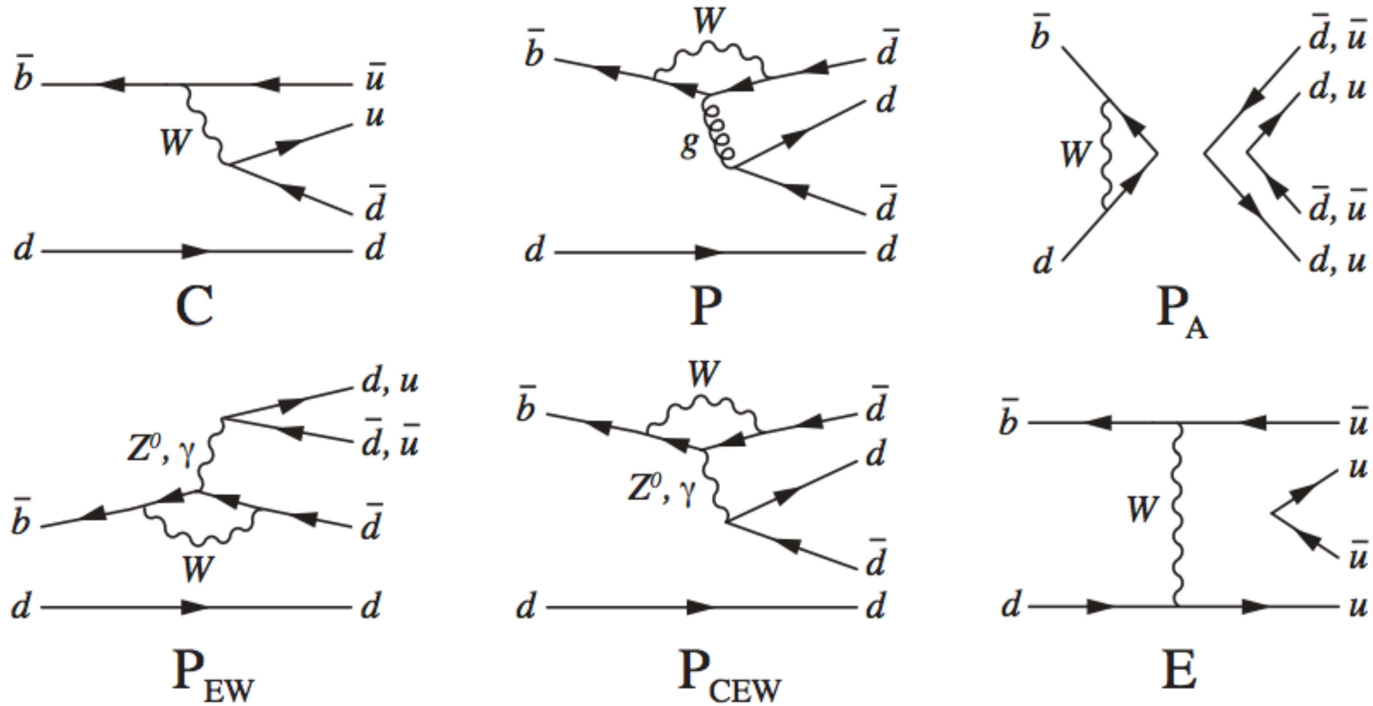
Same diagrams as $B^0 \rightarrow \pi^+\pi^-$ with d←→s exchange (U-spin symmetry)

$$A_{K^+K^-} = D' \frac{\lambda}{1-\lambda^2/2}\left(e^{i\gamma} - \frac{1-\lambda^2}{\lambda^2} d' e^{i\vartheta'}\right) \qquad \bar{A}_{K^+K^-} = D' \frac{\lambda}{1-\lambda^2/2}\left(e^{-i\gamma} - \frac{1-\lambda^2}{\lambda^2} d' e^{i\vartheta'}\right)$$

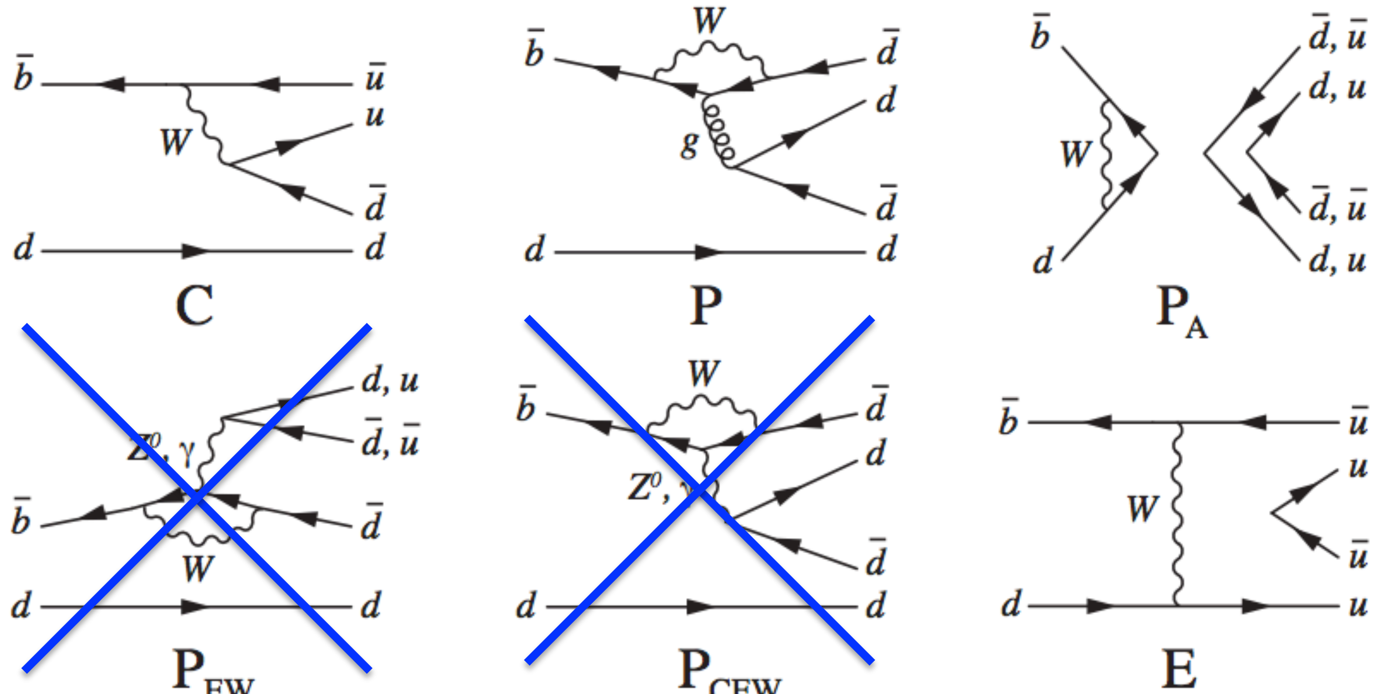
$$D' = A\lambda^3 R_b \left(-\mathrm{T}' - \mathrm{P}'^u - c_u \mathrm{P}'^u_{\mathrm{CEW}} - \mathrm{P}'^u_{\mathrm{A}} + \mathrm{P}'^t + c_u \mathrm{P}'^t_{\mathrm{CEW}} + \mathrm{P}'^t_{\mathrm{A}} - \mathrm{E}'\right)$$

$$G' = A\lambda^3 \left(-\mathrm{P}'^c - c_u \mathrm{P}'^c_{\mathrm{CEW}} - \mathrm{P}'^c_{\mathrm{A}} + \mathrm{P}'^t + c_u \mathrm{P}'^t_{\mathrm{CEW}} + \mathrm{P}'^t_{\mathrm{A}}\right) \qquad d' e^{i\vartheta'} = \frac{G'}{D'}$$

$B^0 \rightarrow \pi^0\pi^0$ decay amplitude



$B^0 \rightarrow \pi^0\pi^0$ decay amplitude

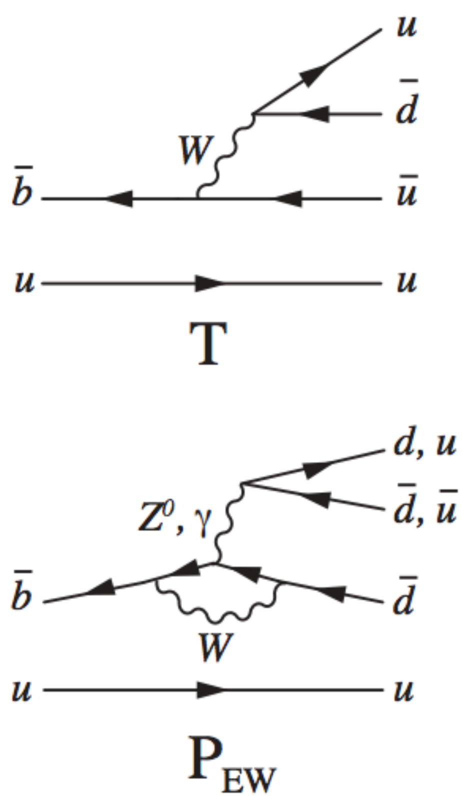


$$A_{\pi^0\pi^0} = \frac{1}{\sqrt{2}} D\left(q e^{i\vartheta_q} e^{i\gamma} + d e^{i\vartheta}\right) \qquad \bar{A}_{\pi^0\pi^0} = \frac{1}{\sqrt{2}} D\left(q e^{i\vartheta_q} e^{-i\gamma} + d e^{i\vartheta}\right)$$

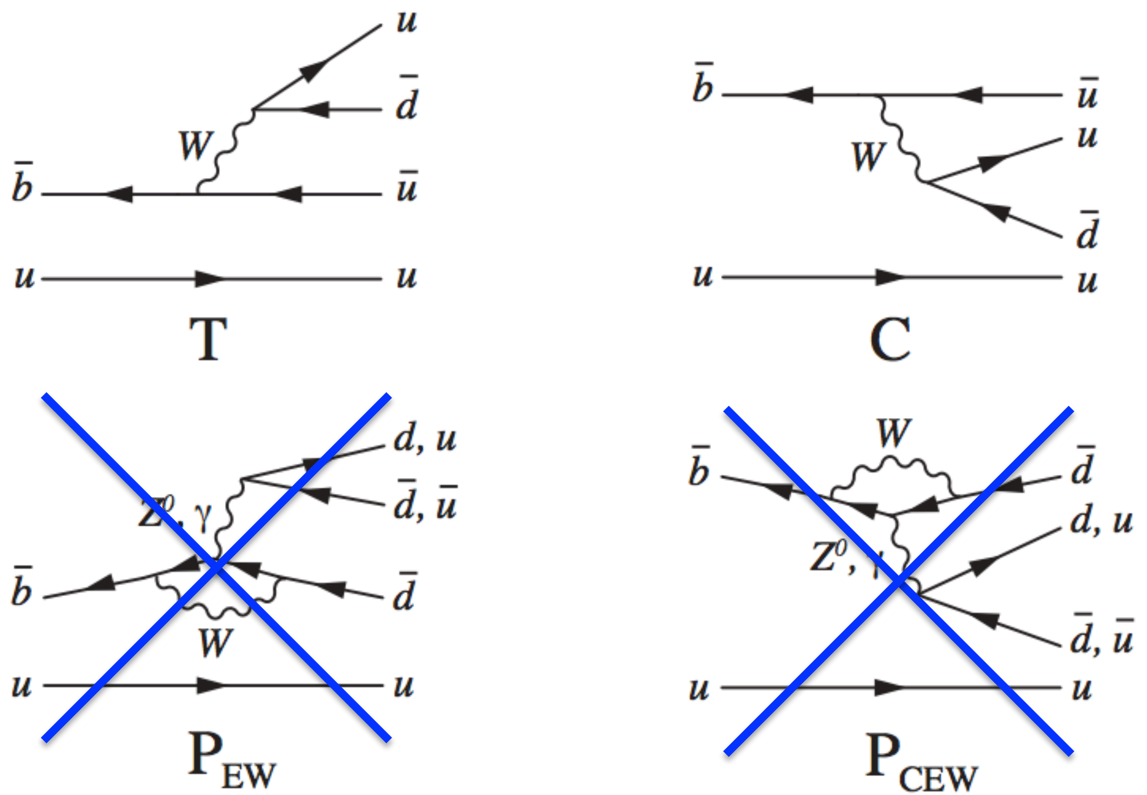
$$H = A\lambda^3 R_b \left[-\mathrm{C} + \mathrm{P}^u + (c_d - c_u)\mathrm{P}^u_{\mathrm{EW}} + c_d \mathrm{P}^u_{\mathrm{CEW}} + \mathrm{P}^u_{\mathrm{A}} - \mathrm{P}^t - (c_d - c_u)\mathrm{P}^t_{\mathrm{EW}} - c_d \mathrm{P}^t_{\mathrm{CEW}} - \mathrm{P}^t_{\mathrm{A}} + \mathrm{E}\right] \qquad q e^{i\vartheta_q} = \frac{H}{D}$$

Assuming isospin and neglecting contributions from EW penguins

$B^+ \to \pi^+\pi^0$ decay amplitude



$B^+ \to \pi^+\pi^0$ decay amplitude



$$A_{\pi^+\pi^0} = \frac{1}{\sqrt{2}} D\left(1 + q e^{i\vartheta_q}\right) e^{i\gamma}, \qquad \bar{A}_{\pi^-\pi^0} = \frac{1}{\sqrt{2}} D\left(1 + q e^{i\vartheta_q}\right) e^{-i\gamma},$$

Assuming isospin and neglecting contributions from EW penguins

Translating amplitudes to CPV coefficients and BRs

$$C_{\pi^+\pi^-} = -\frac{2d\sin(\vartheta)\sin(\gamma)}{1-2d\cos(\vartheta)\cos(\gamma)+d^2}, \qquad S_{\pi^+\pi^-} = -\frac{\sin(2\beta+2\gamma)-2d\cos(\vartheta)\sin(2\beta+\gamma)+d^2\sin(2\beta)}{1-2d\cos(\vartheta)\cos(\gamma)+d^2},$$

$$C_{\pi^0\pi^0} = -\frac{2dq\sin(\vartheta_q-\vartheta)\sin(\gamma)}{q^2+2dq\cos(\vartheta_q-\vartheta)\cos(\gamma)+d^2},$$

Only direct CPV measured for $B^0 \to \pi^0\pi^0$

$$C_{K^+K^-} = \frac{2\tilde{d}'\sin(\vartheta')\sin(\gamma)}{1+2\tilde{d}'\cos(\vartheta')\cos(\gamma)+\tilde{d}'^2}, \qquad S_{K^+K^-} = -\frac{\sin(-2\beta_s+2\gamma)+2\tilde{d}'\cos(\vartheta')\sin(-2\beta_s+\gamma)+\tilde{d}'^2\sin(-2\beta_s)}{1+2\tilde{d}'\cos(\vartheta')\cos(\gamma)+\tilde{d}'^2},$$

$$\mathcal{A}_{\pi^+\pi^0} = 0,$$

Direct CPV in $B^+ \to \pi^+\pi^0$ identically zero

$$\mathcal{B}_{\pi^+\pi^-} = F(B^0\to\pi^+\pi^-)|D|^2(1-2d\cos(\vartheta)\cos(\gamma)+d^2),$$

$$\mathcal{B}_{\pi^+\pi^0} = F(B^+\to\pi^+\pi^0)\frac{|D|^2}{2}(1+q^2+2q\cos(\vartheta_q))$$

$$\mathcal{B}_{\pi^0\pi^0} = F(B^0\to\pi^0\pi^0)\frac{|D|^2}{2}(q^2+2dq\cos(\vartheta_q-\vartheta)\cos(\gamma)+d^2)$$

$$\mathcal{B}_{K^+K^-} = F(B_s^0\to K^+K^-)\frac{\lambda^2}{(1-\lambda^2/2)^2}|D'|^2(1+2\tilde{d}'\cos(\vartheta')\cos(\gamma)+\tilde{d}'^2). \qquad \tilde{d}' = d'(1-\lambda^2)/\lambda^2$$

9 usable constraints in total

Recap

- $C_{\pi+\pi-} = f_1(d, \vartheta, \gamma)$
- $S_{\pi+\pi-} = f_2(d, \vartheta, \gamma, \beta)$
- $C_{K+K-} = f_3(d', \vartheta', \gamma)$
- $S_{K+K-} = f_4(d', \vartheta', \gamma, \beta_s)$
- $C_{\pi0\pi0} = f_5(d, q, \vartheta, \vartheta_q, \gamma)$
- $B_{\pi+\pi-} = f_6(|D|, d, \vartheta, \gamma)$
- $B_{K+K-} = f_7(|D'|, d', \vartheta', \gamma)$
- $B_{\pi0\pi0} = f_8(|D|, d, q, \vartheta, \vartheta_q, \gamma)$
- $B_{\pi+\pi0} = f_9(|D|, q, \vartheta_q)$

CKM angles
γ, β, β_s

Hadronic parameters
$d, \vartheta, d', \vartheta', q, \vartheta_q, |D|, |D'|$

U-spin method

[PLB 459 (1999) 306 and others]

- Using CP asymmetries and BRs of $B^0 \rightarrow \pi^+\pi^-$ and $B_s \rightarrow K^+K^-$
  - 9 unknowns: d, d’, θ, θ', |D|, |D’|, γ, β, $-2\beta_s$
  - 6 constraints: $C_{\pi\pi}$, $S_{\pi\pi}$, $B_{\pi\pi}$, C_{KK}, S_{KK}, B_{KK}
  - Constrain the sign of $A^{\Delta\Gamma}_{KK}$

Experimental inputs

Quantity	Value	Source
$C_{\pi^+\pi^-}$	-0.30 ± 0.05	Our average
$S_{\pi^+\pi^-}$	-0.66 ± 0.06	Our average
$\rho(C_{\pi^+\pi^-}, S_{\pi^+\pi^-})$	-0.007	Our average
$C_{K^+K^-}$	0.14 ± 0.11	LHCb
$S_{K^+K^-}$	0.30 ± 0.13	LHCb
$\rho(C_{K^+K^-}, S_{K^+K^-})$	0.02	LHCb
$\mathcal{B}_{\pi^+\pi^-} \times 10^6$	5.10 ± 0.19	HFAG
$\mathcal{B}_{K^+K^-} \times 10^6$	24.5 ± 1.8	HFAG
$\sin 2\beta$	0.682 ± 0.019	HFAG
m_{B^0} [MeV/c^2]	5279.55 ± 0.26	PDG
$m_{B^0_s}$ [MeV/c^2]	5366.7 ± 0.4	PDG
m_{π^+} [MeV/c^2]	139.57018 ± 0.00035	PDG
m_{K^+} [MeV/c^2]	493.677 ± 0.013	PDG
τ_{B^0} [ps]	1.519 ± 0.007	HFAG
$\tau_{B^0_s}$ [ps]	1.516 ± 0.011	HFAG
$\Delta\Gamma_s/\Gamma_s$	0.160 ± 0.020	LHCb
$\tau(B^0_s \to K^+K^-)$ [ps]	1.452 ± 0.042	LHCb

$$A^{\Delta\Gamma}_{K^+K^-} = -\frac{\cos(-2\beta_s + 2\gamma) + 2\tilde{d}' \cos(\vartheta') \cos(-2\beta_s + \gamma) + \tilde{d}'^2 \cos(-2\beta_s)}{1 + 2\tilde{d}' \cos(\vartheta') \cos(\gamma) + \tilde{d}'^2} < 0$$

LHCb-PAPER-2014-011

- Need to assume U-spin symmetry to reduce the number of unknown parameters

U-spin method

- $B^0 \rightarrow \pi^+\pi^-$ and $B_s \rightarrow K^+K^-$ are U-spin symmetry partners
- Assuming perfect U-spin symmetry one gets
  - $d = d'$, $\theta = \theta'$, $|D| = |D'|$
- The equalities $d = d'$ and $\theta = \theta'$ do not receive U-spin breaking corrections within factorization
  - But non-factorizable U-spin contributions may still be large
- By contrast, the U-spin equality $|D| = |D'|$ is already broken in factorization
- Using QCD sum rules one has $\left|\frac{D'}{D}\right|_{\text{fact}} = 1.41^{+0.20}_{-0.11}.$

[PRD 78 (2008) 054015]

U-spin method

(determination of angle γ)

- One further unknown can be eliminated by substituting $-2\beta_s$ in the equations with its SM expression

SM expression of $-2\beta_s$ up to λ^4 terms

$$-2\beta_s = -2\lambda^2\bar{\eta}\left[1+\lambda^2\left(1-\bar{\rho}\right)\right]$$

$$\bar{\rho} = \frac{\sin\beta\cos\gamma}{\sin(\beta+\gamma)} \qquad \bar{\eta} = \frac{\sin\beta\sin\gamma}{\sin(\beta+\gamma)}$$

Parameters extracted with flat priors →

Quantity	Prior range
d	$[0,\ 20]$
ϑ	$[-180°,\ 180°]$
γ	$[-180°,\ 180°]$

Note: |D| is eliminated by solving eq. $\mathcal{B}_{\pi^+\pi^-} = F(B^0\to\pi^+\pi^-)|D|^2(1-2d\cos(\vartheta)\cos(\gamma)+d^2)$,

Note: |D'| is eliminated by $|D'| = \left|\frac{D'}{D}\right|_{fact.}|D|$

U-spin method

(determination of $-2\beta_s$)

- In order to determine $-2\beta_s$ we constrain the γ angle to the world average value from tree decays whereas $-2\beta_s$ is left as a free parameter

$$\gamma = (70.1 \pm 7.1)^\circ$$

Average of BaBar, Belle and LHCb (by UTFit)

Note: |D| is eliminated solving the equation

$$\mathcal{B}_{\pi^+\pi^-} = F(B^0 \to \pi^+\pi^-)|D|^2(1 - 2d\cos(\vartheta)\cos(\gamma) + d^2),$$

Note: |D'| is eliminated using the equation

$$|D'| = \left|\frac{D'}{D}\right|_{fact.} |D|$$

Parameters extracted with flat priors

Quantity	Prior range
d	$[0,\ 20]$
ϑ	$[-180^\circ,\ 180^\circ]$
$-2\beta_s[rad]$	$[-\pi, \pi]$

Effect of non-factorizable U-spin breaking

- Non-factorizable U-spin breaking effects are parameterized by

$$|D'| = \left|\frac{D'}{D}\right|_{\rm fact} |D| \; \left|1 + r_D e^{i\vartheta_{r_D}}\right|,$$

$$d' e^{i\vartheta'} = d e^{i\vartheta} \frac{1 + r_G e^{i\vartheta_{r_G}}}{1 + r_D e^{i\vartheta_{r_D}}}.$$

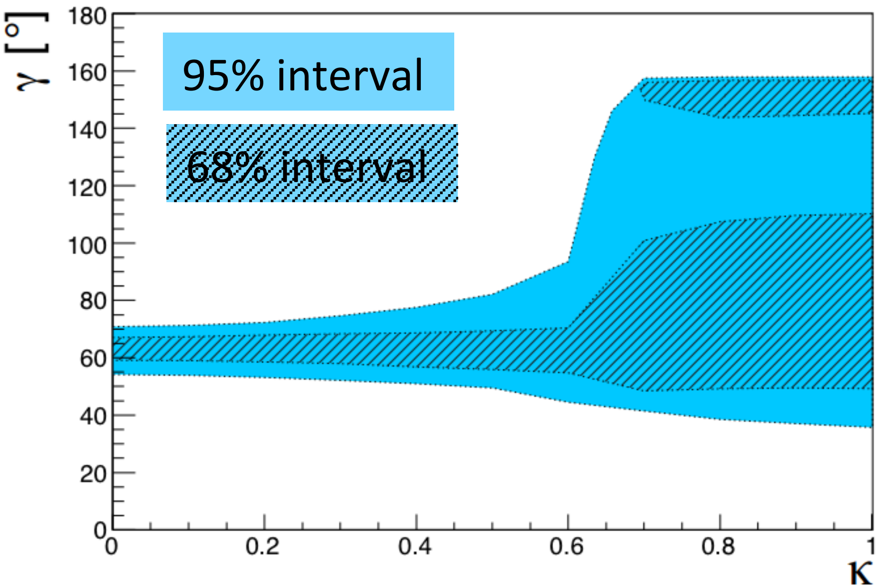
r_D and r_G are relative magnitudes and θ_{rD} and θ_{rG} are strong phase shifts caused by the breaking

- Flat priors on U-spin breaking parameters
  - **r_D = [0, κ], r_G = [0,κ]**
  - **θ_{rD} = [-π,π], θ_{rG} = [-π,π]**
- κ represents the maximum non-factorizable U-spin breaking allowed for in the analysis
  - Sloppily speaking: κ = 0.3 corresponds to up to 30% breaking

Effect of non-factorizable U-spin breaking

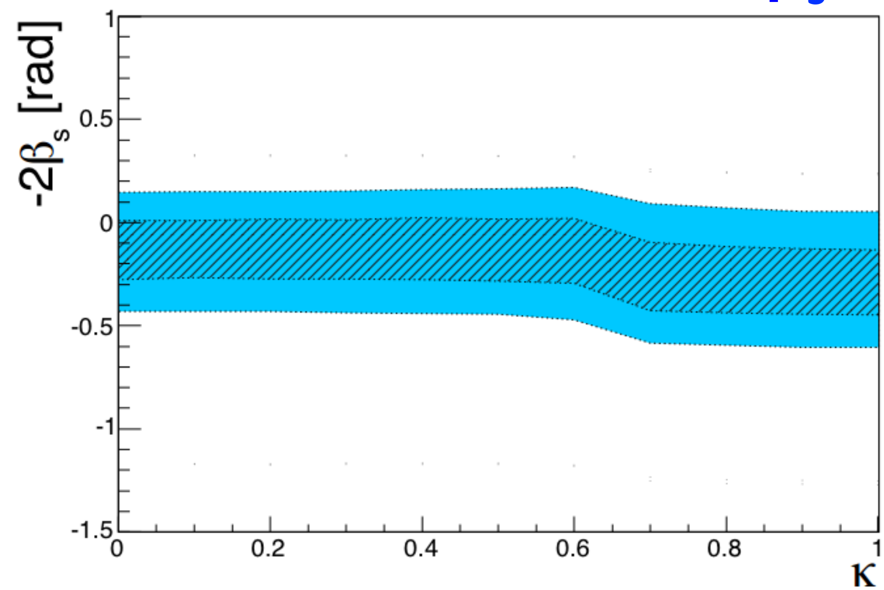
(U-spin method)

Determination of γ



- Sensitivity on γ is good up to $\kappa = 0.6$
- For $\kappa > 0.6$ sensitivity on γ deteriorates very quickly

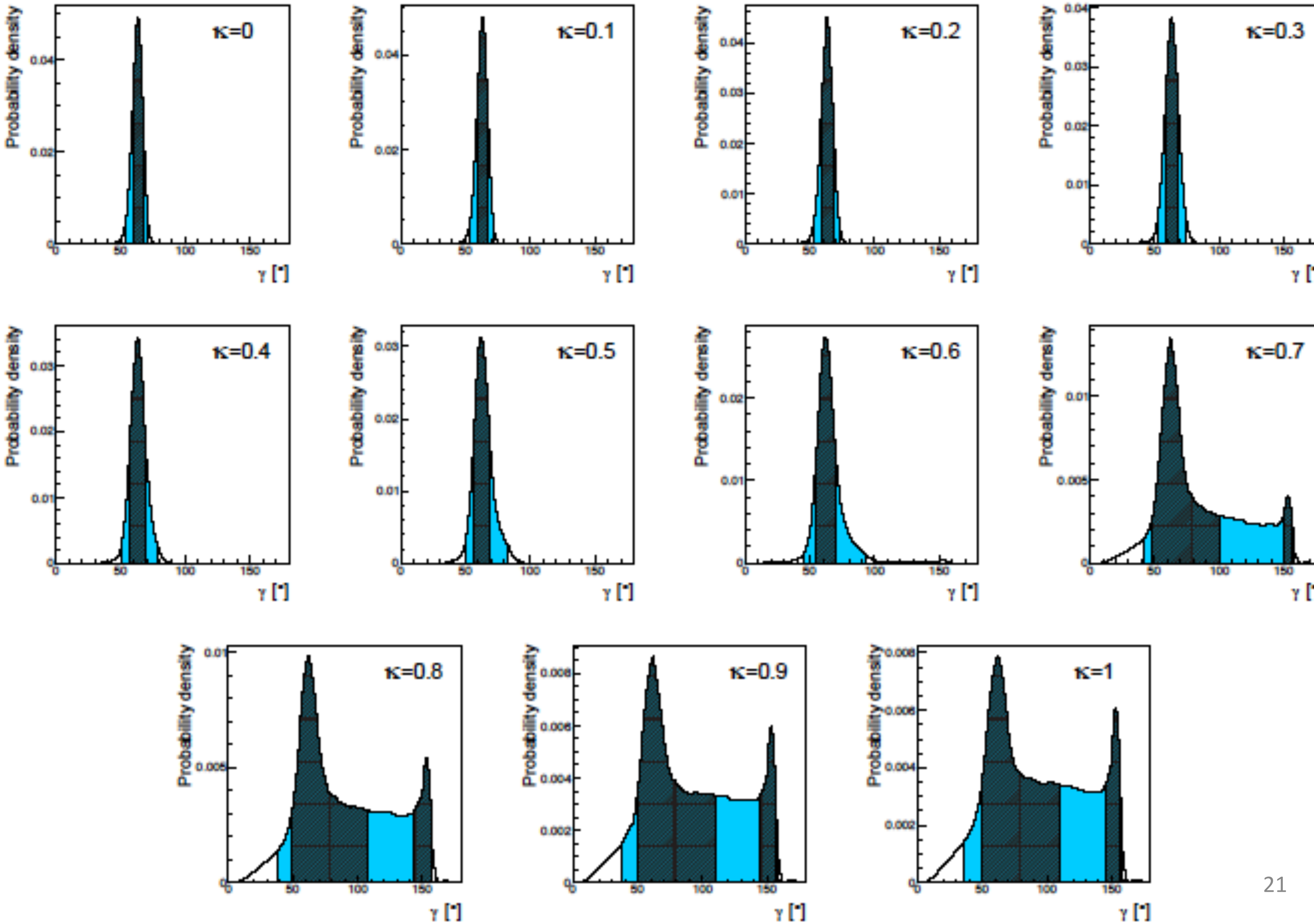
Determination of $-2\beta_s$



- Sensitivity on $-2\beta_s$ almost unaffected up to $\kappa = 1$, but shifted toward decreasing values for $\kappa > 0.6$

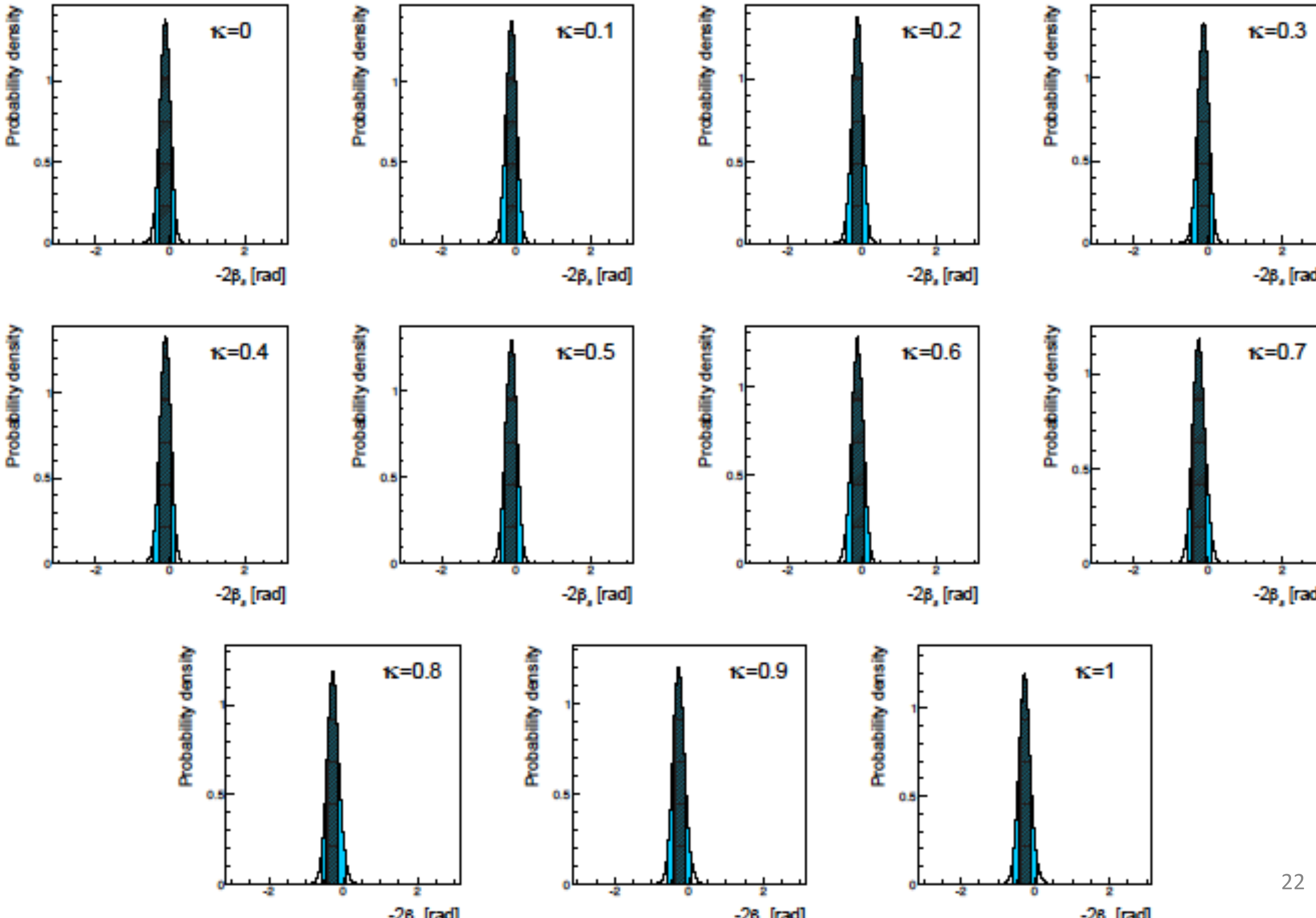
PDF for γ vs U-spin breaking

(U-spin method)



PDF for $-2\beta_s$ vs U-spin breaking

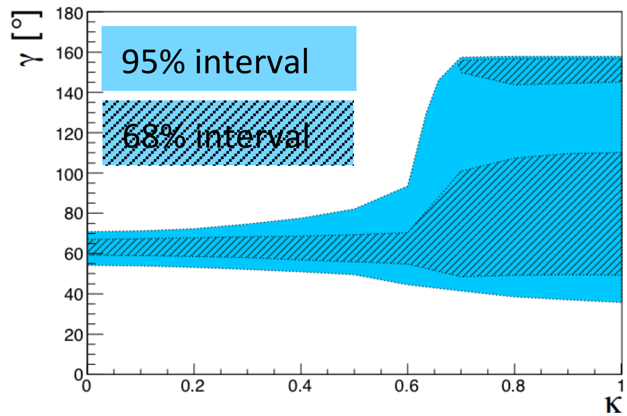
(U-spin method)

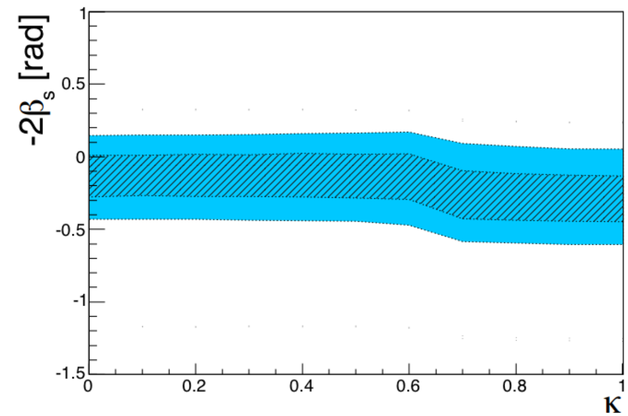


Inclusion of $B^+ \rightarrow \pi^+\pi^0$ and $B^0 \rightarrow \pi^0\pi^0$

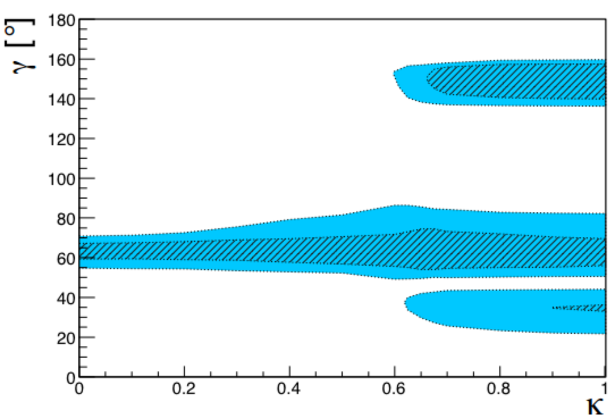
(following JHEP 10 (2012) 029)

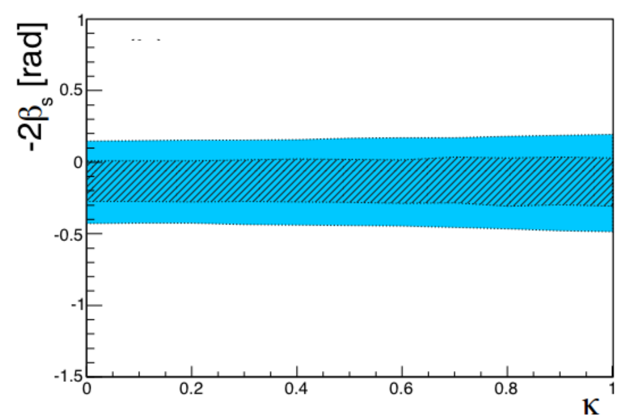
Information from $B^+ \rightarrow \pi^+\pi^0$ and $B^0 \rightarrow \pi^0\pi^0$ helps to better control non-factorizable U-spin breaking effects





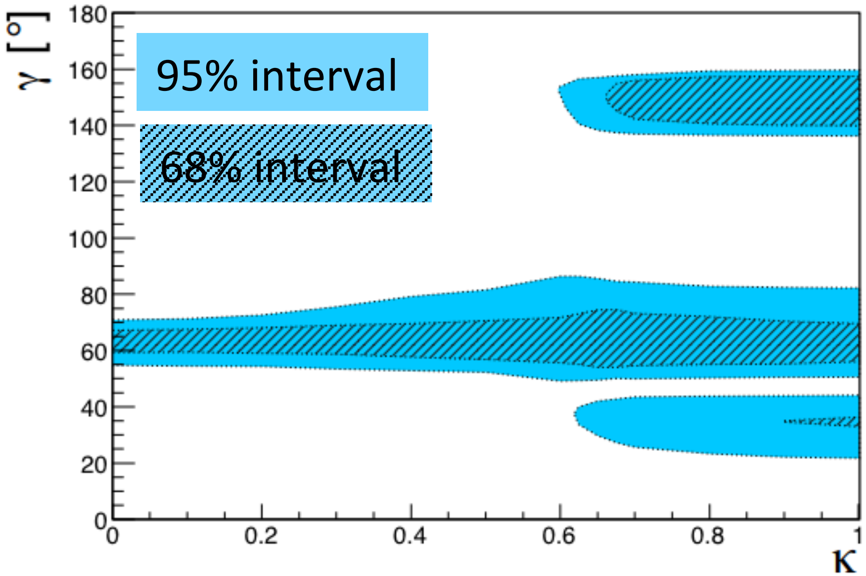
Including $B^+ \rightarrow \pi^+\pi^0$ and $B^0 \rightarrow \pi^0\pi^0$

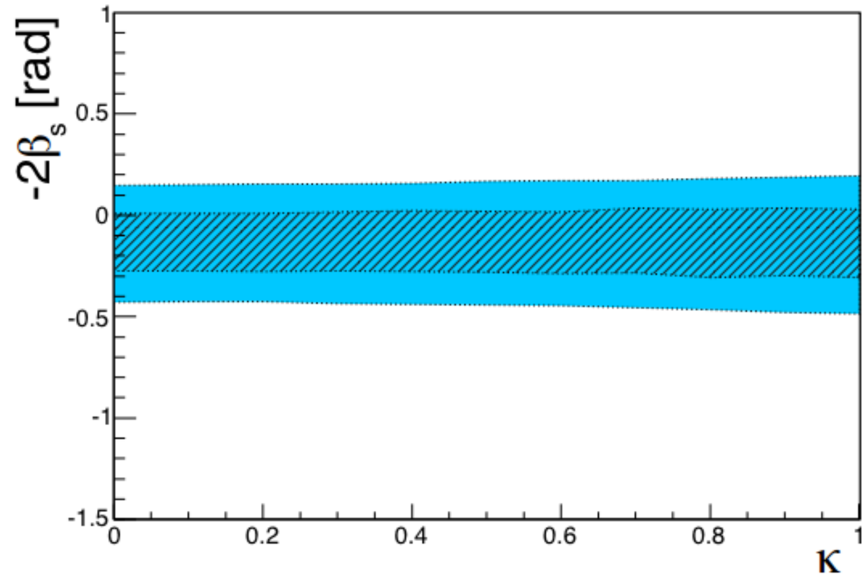




Inclusion of $B^+ \rightarrow \pi^+\pi^0$ and $B^0 \rightarrow \pi^0\pi^0$

(following JHEP 10 (2012) 029)

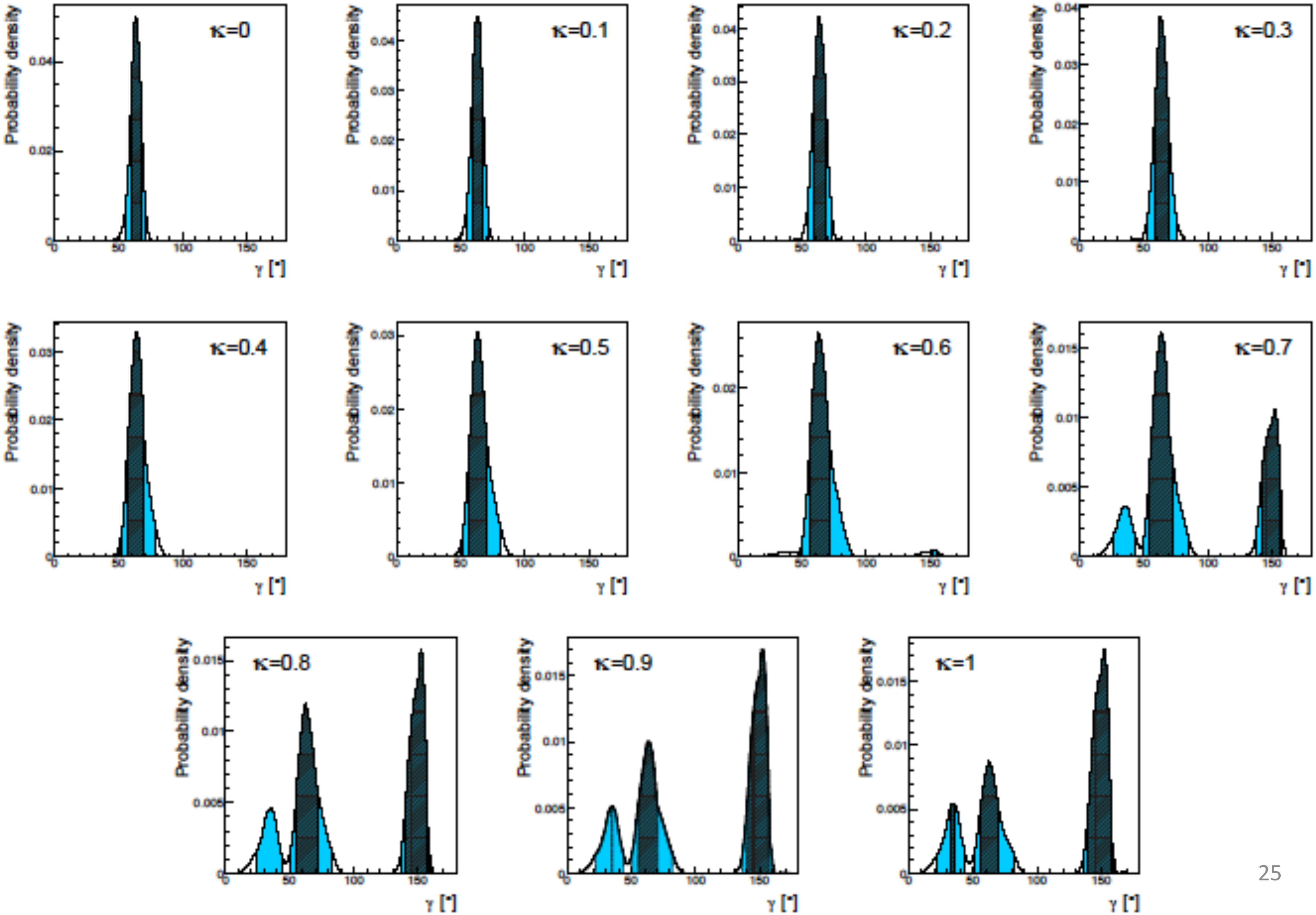




- Better control of non factorizable U-spin breaking effects for $\kappa > 0.6$ but still multiple nonzero probability regions appear
- The shift towards decreasing values of $-2\beta_s$ for $\kappa > 0.6$ disappears completely → robust determination up to 100% non-factorizable U-spin breaking

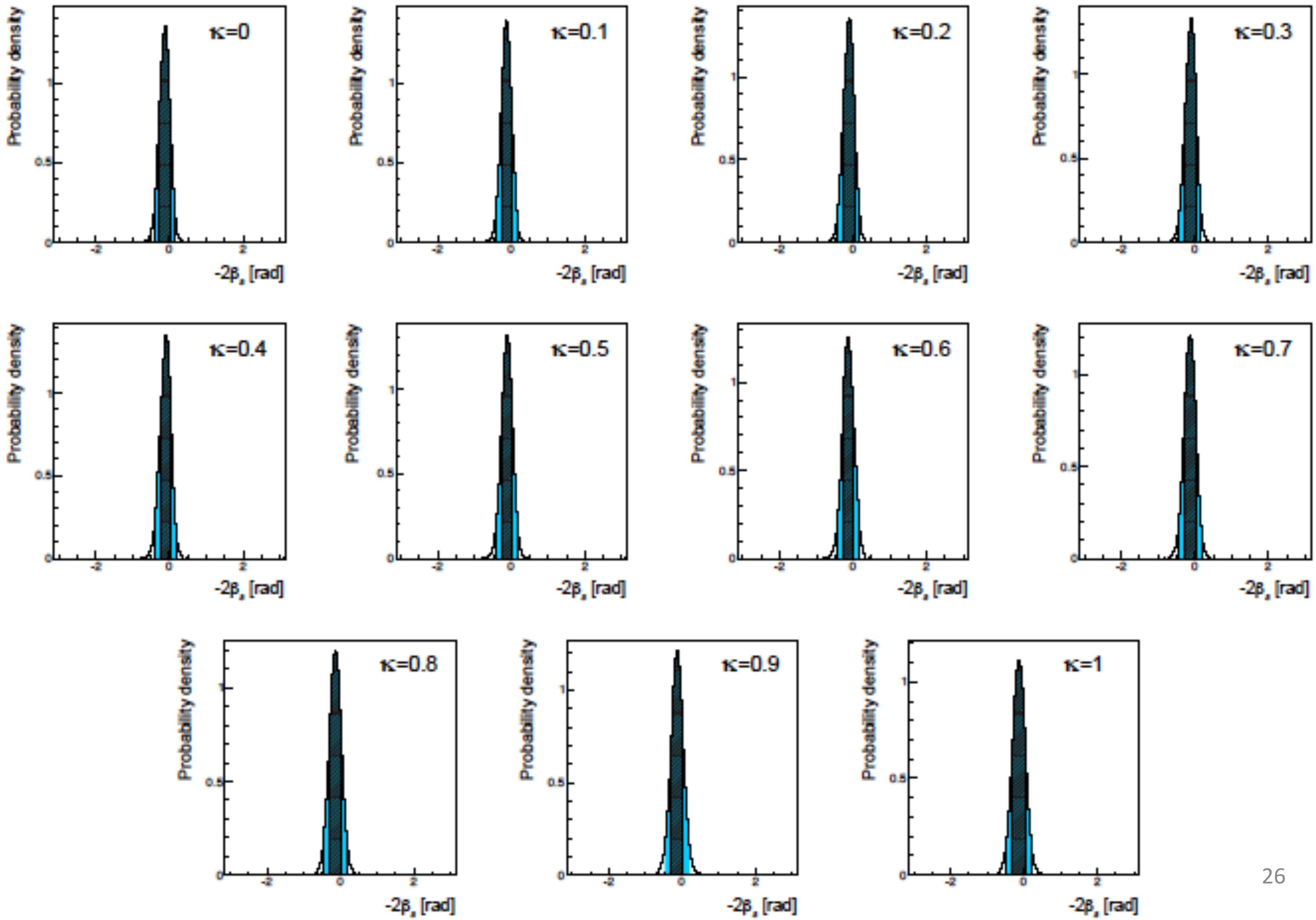
PDF for γ vs U-spin breaking

(following JHEP 10 (2012) 029)



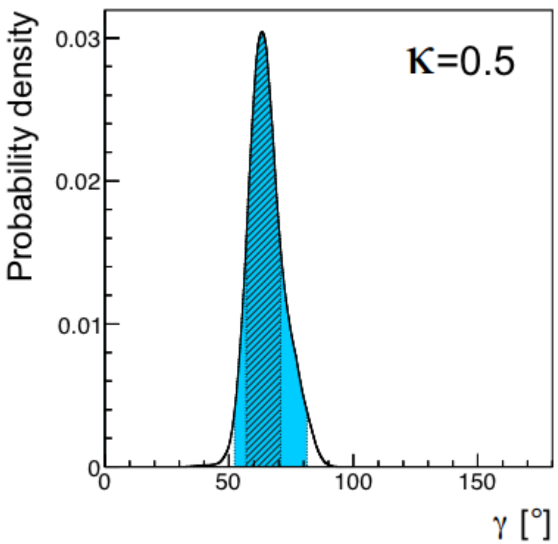
PDF for $-2\beta_s$ vs U-spin breaking

(following JHEP 10 (2012) 029)

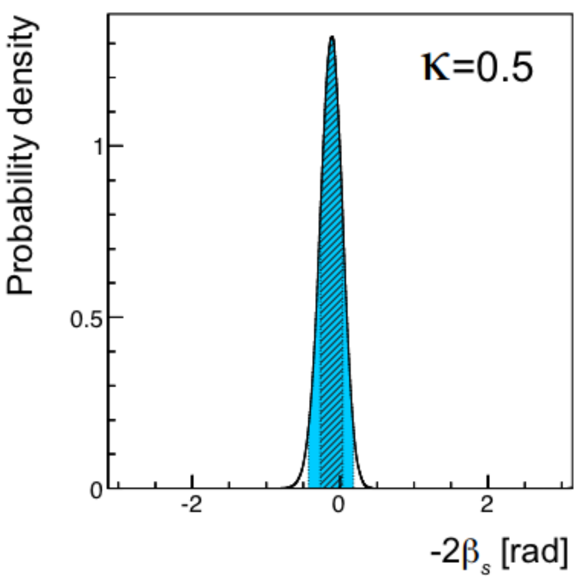


Numerical results for 50% U-spin breaking

(following JHEP 10 (2012) 029)



Quantity	Result at 68% prob.	Result at 95% prob.
d	$[0.33, 0.57]$	$[0.28, 0.79]$
ϑ	$[139°, 157°]$	$[125°, 164°]$
d'	$[0.34, 0.50]$	$[0.28, 0.65]$
ϑ'	$[132°, 160°]$	$[119°, 176°]$
q	$[1.04, 1.21]$	$[0.94, 1.30]$
ϑ_q	$[-82°, -58°]$	$[-88°, -35°]$
$\lvert D\rvert$ $[\mathrm{MeV}^{\frac{1}{2}}\,\mathrm{ps}^{-\frac{1}{2}}]$	$[0.101, 0.113]$	$[0.094, 0.118]$
$\lvert D'\rvert$ $[\mathrm{MeV}^{\frac{1}{2}}\,\mathrm{ps}^{-\frac{1}{2}}]$	$[0.129, 0.193]$	$[0.097, 0.228]$
γ	$[57°, 71°]$	$[52°, 82°]$



Quantity	Result at 68% prob.	Result at 95% prob.
d	$[0.37, 0.59]$	$[0.31, 0.77]$
ϑ	$[142°, 157°]$	$[132°, 163°]$
d'	$[0.34, 0.52]$	$[0.29, 0.70]$
ϑ'	$[133°, 160°]$	$[119°, 176°]$
q	$[1.04, 1.21]$	$[0.95, 1.30]$
ϑ_q	$[-78°, -57°]$	$[-85°, 38°]$
$\lvert D\rvert$ $[\mathrm{MeV}^{\frac{1}{2}}\,\mathrm{ps}^{-\frac{1}{2}}]$	$[0.100, 0.111]$	$[0.094, 0.116]$
$\lvert D'\rvert$ $[\mathrm{MeV}^{\frac{1}{2}}\,\mathrm{ps}^{-\frac{1}{2}}]$	$[0.122, 0.187]$	$[0.089, 0.221]$
$-2\beta_s$ [rad]	$[-0.28, 0.02]$	$[-0.44, 0.17]$

Summary

- The determination of γ and $-2\beta_s$ using the decays $B^0 \to \pi^+\pi^-$, $B^0 \to \pi^0\pi^0$, $B^\pm \to \pi^\pm\pi^0$ and $B_s \to K^+K^-$ has been studied
- Two methods have been applied
  - The first as in **PLB 459 (1999) 306**
    - uses observables only from $B^0 \to \pi^+\pi^-$ and $B_s \to K^+K^-$
    - relies on the use of U-spin symmetry
  - The second as in **JHEP 10 (2012) 029**
    - uses also information from $B^0 \to \pi^0\pi^0$ and $B^\pm \to \pi^\pm\pi^0$
    - relies on the use of both isospin and U-spin symmetries

Summary

- The impact of non-factorizable U-spin breaking corrections on the determination of γ and $-2\beta_s$ has been studied up to 100% breaking

- The two methods give similar results with up to ~50% breaking

  – The inclusion of information from $B^+ \to \pi^+\pi^0$ and $B^0 \to \pi^0\pi^0$ gives more robust results against non-factorizable U-spin breaking values larger than 50%

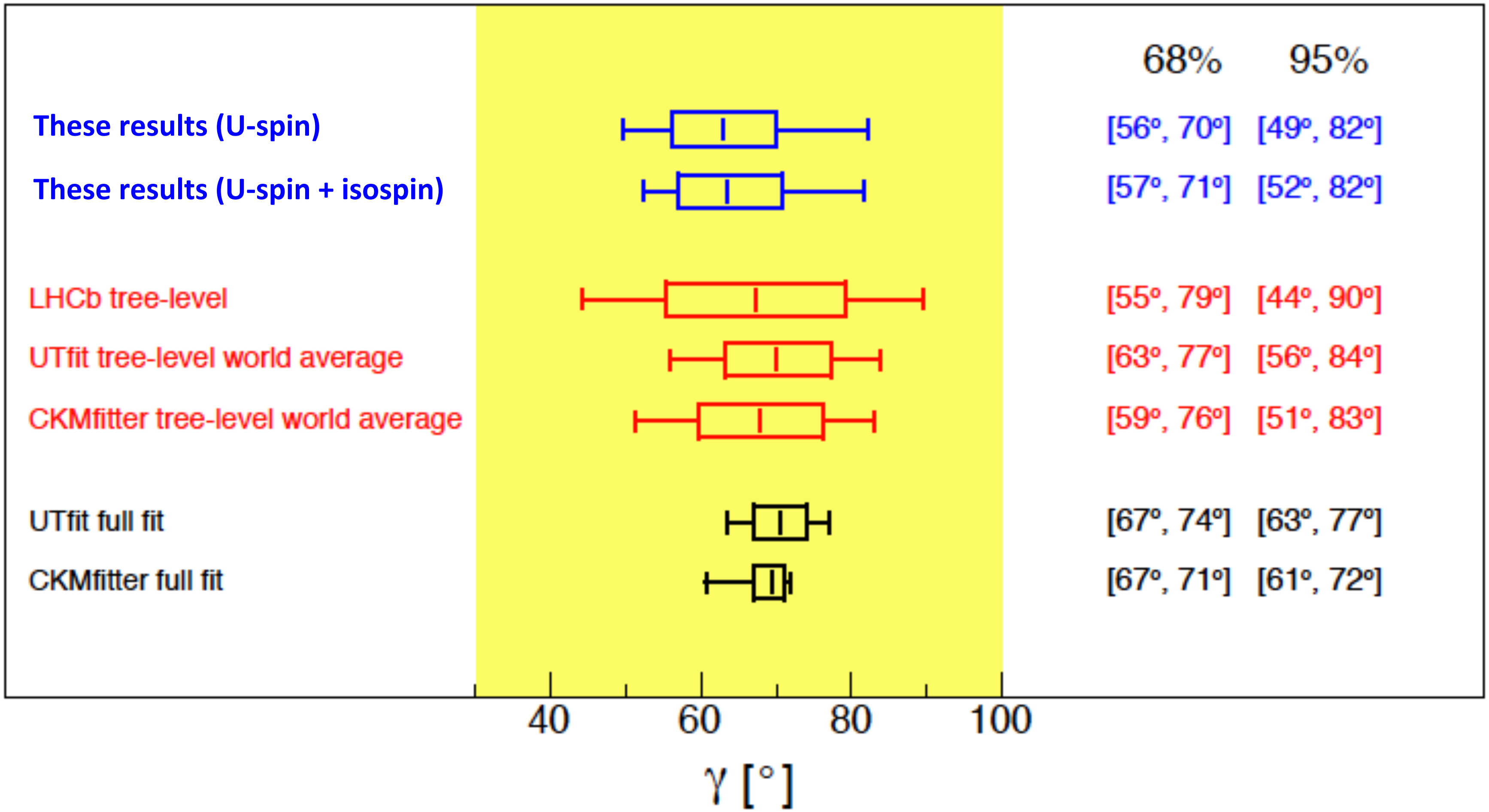
$$\gamma = \left(63.5^{+7.2}_{-6.7}\right)^\circ$$

$$-2\beta_s = -0.12^{+0.14}_{-0.16} \text{ rad}$$

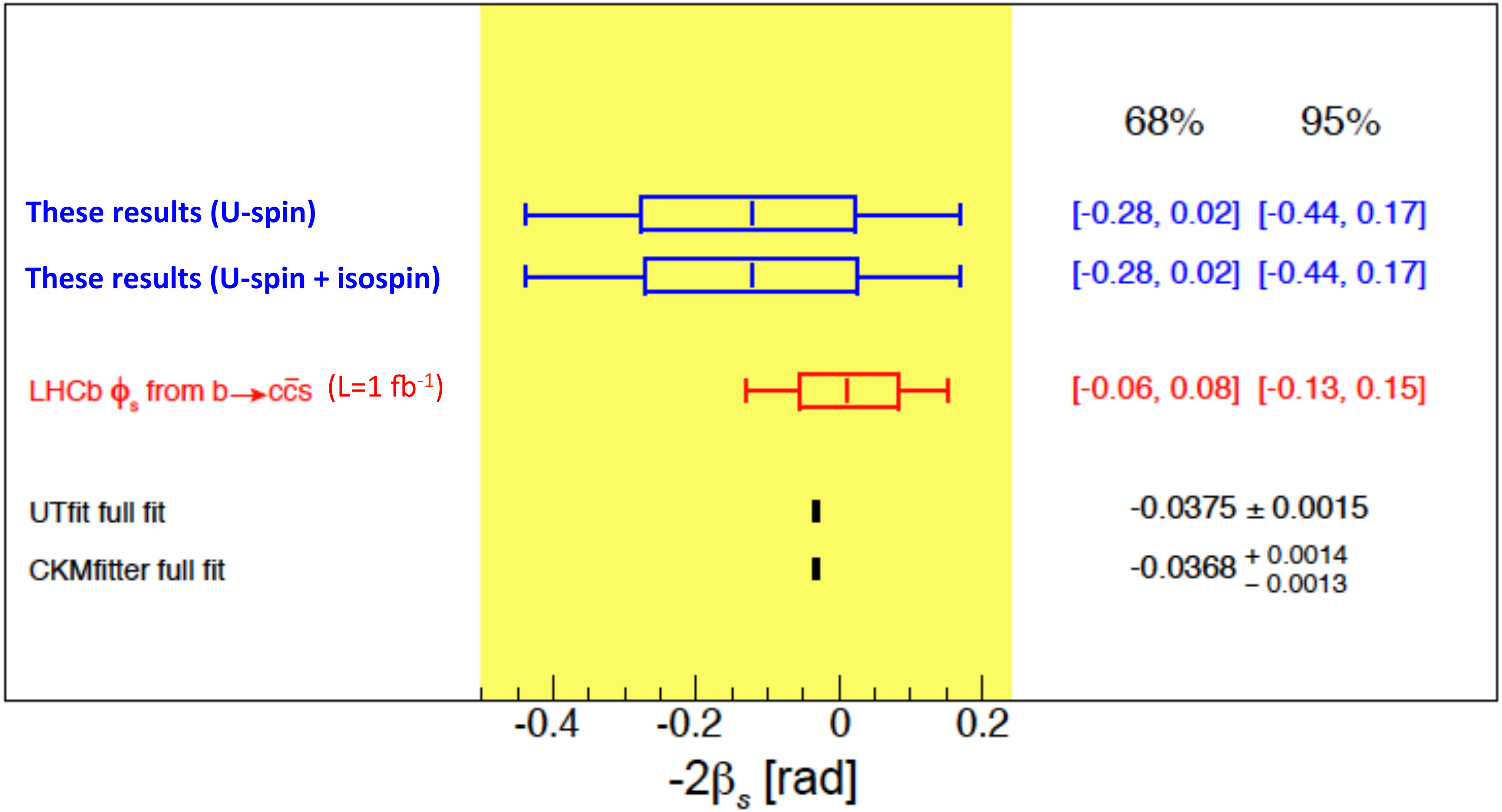
Up to 50% non-factorizable U-spin breaking effects allowed for

- The results have been checked to be robust with respect to the choice of priors and of the adopted parameterization of U-spin breaking

Summary table for γ
(50% non-factorizable U-spin breaking included)



Summary table for $-2\beta_s$ (50% non-factorizable U-spin breaking included)



Conclusions

- Determination of γ from charmless two-body *B* decays is compatible and competitive with tree-level determination if non-factorizable U-spin breaking up to 50% is allowed for
  - **However, due to the impact of U-spin symmetry breaking, this measurement will only improve slightly with additional statistics, as sensitivity quickly saturates with such a large level of breaking**
- **The impact of U-spin breaking on the determination of $-2\beta_s$ is much smaller than for γ**
  - **up to 100% non-factorizable breaking, the correction is marginal**
  - The current uncertainty is **only 50% larger** with respect to that obtained from the golden $B_s \rightarrow J/\psi KK$ mode, at equal luminosity of $B_s \rightarrow K^+K^-$ measurement (1 fb^{-1} so far)
  - Significant improvements are expected by increasing the statistics
    - Update of $B_s \rightarrow K^+K^-$ CPV analysis to full 3 fb^{-1} ongoing

Questions to theory

- Are you comfortable with O(50%) U-spin breaking?
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- Are you comfortable with O(50%) U-spin breaking?
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- If not, are you comfortable with 100%?
- Can we make anything better?