CP Violation sensitivity at the Belle II Experiment

A.Mordá

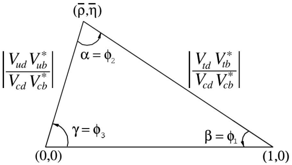
on behalf of the Belle2 Collaboration

INFN - Padova

7^{th} July 2017

CP Violation (CPV) in the Standard Model (SM)

The B^0 Unitarity Triangle (UT)

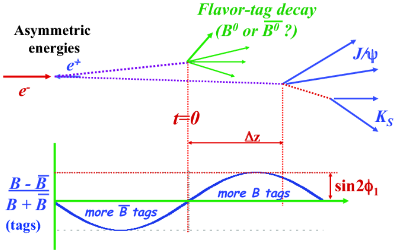


Two angles depend on top-beauty coupling accessible through B^0 oscillation processes

$$\alpha^{WA}|_{1\sigma} = (88.8^{+2.3}_{-2.3})^\circ \quad , \quad \beta^{WA}|_{1\sigma} = (21.85^{+0.68}_{-0.67})^\circ$$

[CKMFitter, Summer '16]

Asymmetric *B-factories* @ $\Upsilon(4S)$



$$\Delta t \simeq \Delta z/\beta\gamma c$$

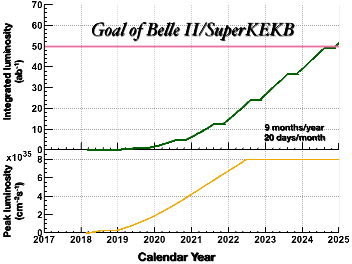
Time dependent rate asymmetry of B meson decays into CP eigenstates

$$a_{f_{CP}}(\Delta t) \equiv \frac{\Gamma[B(\Delta t)] - \Gamma[\bar{B}(\Delta t)]}{\Gamma[B(\Delta t)] + \Gamma[\bar{B}(\Delta t)]} = C\cos(\Delta M \Delta t) - S\sin(\Delta M \Delta t)$$

C : Direct CPV $\qquad$ $S \equiv \sin(2\phi_i^{eff})$: mixing induced CPV

SuperKEKB & the Belle 2 detector

- $CPV \sim \frac{1}{\mathcal{BR}} \Rightarrow$ large statistic samples

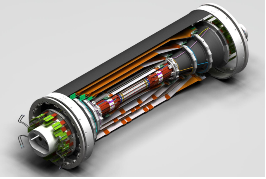


	KEKB	SuperKEKB
$\mathcal{L}\ (10^{34} s^{-1} \cdot cm^{-2})$	2.11	80
$\int \mathcal{L}$dt (ab^{-1})	0.8	50
e^+ energy (GeV)	8	7
e^- energy (GeV)	3.5	4
$\beta\gamma$	0.45	0.28
$< \Delta z >$	$\sim 200\ \mu$m	$\sim 130\ \mu$m

- reduced $\Upsilon(4S)$ boost
- higher background

} **Pixel detector**

factor 2 improvement in vertexing achievable

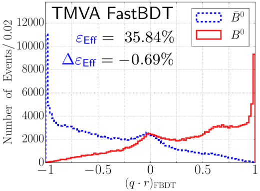


Resolution	Belle	Belle2
$J/\psi \to \mu\mu$	43μm	25.6μm
Tag side	89μm	53μm
Δt	0.92 ps	0.77 ps

Two benchmark scenarios:

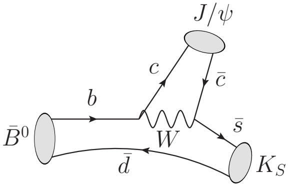
- **Syst 1**: no improvement
- **Syst 2**: factor 2 improvement

- **Efficient Flavor Tagger**



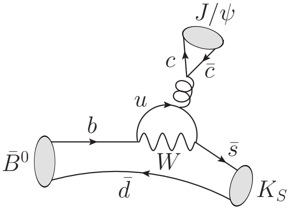
$\sin(2\beta)$ in tree dominated $b \to c\bar{c}s$ transitions

One dominant weak phase



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

Penguin pollution



Current status from Belle

[PRL 108 171802]		Value	stat (10^{-3})	syst (10^{-3})
$J/\psi K_S^0$	S	+0.67	29	13
	$\mathcal{A} \equiv -C$	-0.015	21	+45,-23
$c\bar{c}s$	S	+0.667	23	12
	$\mathcal{A} \equiv -C$	+0.006	16	12

$S(C)$ is statistically (systematically) dominated

Irreducible systematics from vertexing & tag-side interference

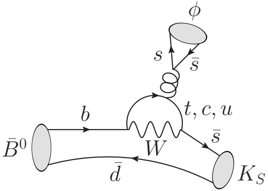
Belle2 expected uncertainties @ 50 ab^{-1}

Expected errors (10^{-3})		stat	syst reducible	Syst 1	Syst 2
$J/\psi K_S^0$	S	3.5	1.2	8.2	4.4
	$\mathcal{A} \equiv -C$	2.5	0.7	+43,-22	+42, - 11
$c\bar{c}s$	S	2.7	2.6	7.0	3.6
	$\mathcal{A} \equiv -C$	1.9	1.4	10.6	8.7

Precision better than 1% is expected on β from $b \to c\bar{c}s$

$\sin(2\beta)$ in penguin dominated $b \to q\bar{q}s$: $B^0 \to \phi K^0$

Loop process, same weak phase as $b \to c\bar{c}s$



Current status from Belle: $S_{\phi K_S^0} = +0.9^{+0.09}_{-0.19}$

Expected sensitivity @ 5 ab^{-1}

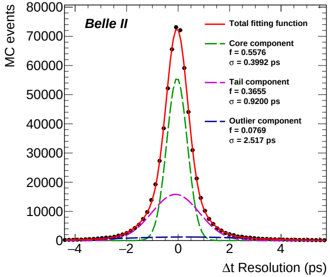
Channel	$\sigma(S)$	$\sigma(C)$
$\phi(K^+K^-)K_S^0(\pi^+\pi^-)$	0.078	0.055
$\phi(K^+K^-)K_S^0(\pi^0\pi^0)$	0.132	0.096
$\phi(\pi^+\pi^-\pi^0)K_S^0(\pi^+\pi^-)$	0.151	0.113
K_S^0 modes	0.060	0.044
$K_S^0 + K_L^0$ modes	0.048	0.035

Sensitivity studies without beam induced background

Time resolution of benchmark modes

Channel	Δt resolution (ps)
$\phi(K^+K^-)K_S^0(\pi^+\pi^-)$	0.75
$\phi(K^+K^-)K_S^0(\pi^0\pi^0)$	0.77
$\phi(\pi^+\pi^-\pi^0)K_S^0(\pi^+\pi^-)$	0.78

$\Delta t^{rec} - \Delta t^{MC}$ in $\phi(K^+K^-)K_S^0(\pi^+\pi^-)$



sin (2β) in penguin dominated $b \to q\bar{q}s$: $B^0 \to \eta' K^0$

Current status from Belle: $S_{\eta' K^0_S} = +0.68 \pm 0.07 \pm 0.03$ [JHEP 10 165]

Crucial aspect is $\boldsymbol{\pi^0, \eta^0}$ reconstruction

Non negligible fraction of mis-reconstructed signal (**SxF**)

Sensitivity studies accounting for beam induced background

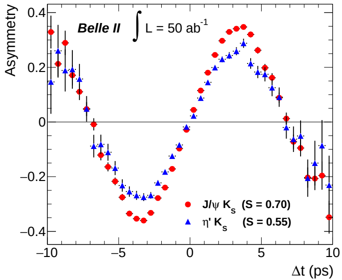
Expected sensitivity @ 5 ab^{-1}

Channel	$\sigma(S)$	$\sigma(C)$
$\eta'(\eta_{\gamma\gamma}\pi^+\pi^-)K^0_S(\pi^+\pi^-)$	0.06	0.04
$\eta'(\eta_{3\pi}\pi^+\pi^-)K^0_S(\pi^+\pi^-)$	0.11	0.08
K^0_S modes	0.028	0.021
K^0_L modes	0.08	0.05
$K^0_S + K^0_L$ modes	0.027	0.020
Syst	**0.021** (**0.017**)	

Syst 1 (2) scenarios

Time resolution of benchmark modes

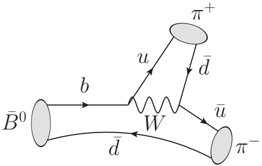
Channel	True	SxF	All
$\eta'(\eta_{\gamma\gamma}\pi^+\pi^-)K^0_S(\pi^+\pi^-)$	1.22 ps	2.87 ps	1.45 ps
$\eta'(\eta_{3\pi}\pi^+\pi^-)K^0_S(\pi^+\pi^-)$	1.17 ps	2.36 ps	1.50 ps

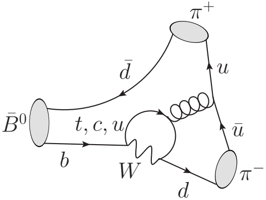


$B^0 \to \eta' K^0$ is the first $b \to q\bar{q}s$ mode systematic dominated @ $\mathcal{L} \sim 10(20)$ ab^{-1}

$\sin(2\alpha)$ measurement: isospin analysis in $B \to \pi\pi, \rho\rho$

Two amplitudes of comparable size and different weak phase





Time dependent $B^0 \to \pi^+\pi^-$ analysis measures

$$\alpha_{eff} = \alpha + \delta\alpha_{peng}$$

Estimate penguin contribution exploiting isospin relation among

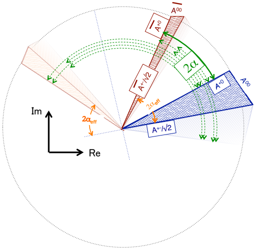
$$A^{(i,j)} \equiv \mathcal{A}(B^{i+j} \to h^i h^j) \;(h = \pi, \rho \;/\; i,j = \pm, 0)$$

$$\boldsymbol{A^{+-}/\sqrt{2} + A^{00} = A^{+0}}$$

$$\boldsymbol{\bar{A}^{+-}/\sqrt{2} + \bar{A}^{00} = \bar{A}^{+0}}$$

$$\boldsymbol{|A^{+0}| = |\bar{A}^{+0}|}$$

Gronau-London method [PRL 64 3381 (1990)]



Picture from [arXiv:1705.02981]

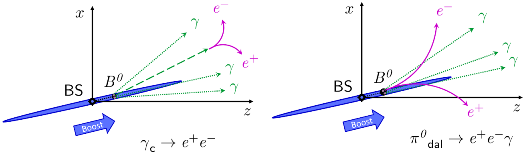
$$\alpha_{eff} = \widehat{(\bar{A}^{+-}, A^{+-})}, \; \alpha = \widehat{(\bar{A}^{+0}, A^{+0})}$$

- measure rates to construct the two triangles
- measure asymmetries to fix their relative position
- $S_{\pi^+\pi^-}$ leaves an 8-fold ambiguity in α
- fixed by **time dependent $B^0 \to \pi^0\pi^0$ analysis**

sin (2α) measurement: $B \to \pi^0\pi^0$ sensitivity

First attempt to measure $S_{\pi^0\pi^0}$

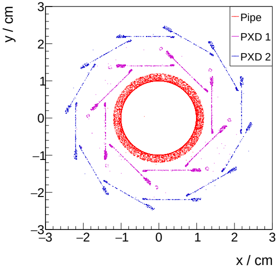
- $B^0_{\rm sig} \to \pi^0_{\gamma\gamma}(\to \gamma\gamma)\ \pi^0_{\gamma\gamma}(\to \gamma\gamma)$
- $B^0_{\rm sig} \to \pi^0_{\rm dal}(\to e^+e^-\gamma)\ \pi^0_{\gamma\gamma}(\to \gamma\gamma)$
- $B^0_{\rm sig} \to \pi^0_{\gamma_c\gamma}(\to \gamma_c(\to e^+e^-)\gamma)\ \pi^0_{\gamma\gamma}(\to \gamma\gamma)$

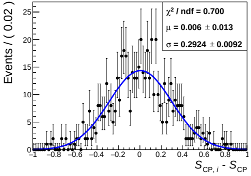


- Reconstruction efficiency is crucial
- Statistical uncertainty estimated through MC toys

$$\sigma(S) \sim 0.29$$

Conversion vertices in the innermost part of detector

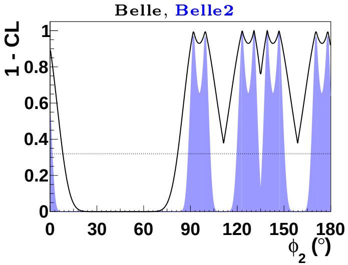




sin (2α) measurement: $B \to \pi\pi$

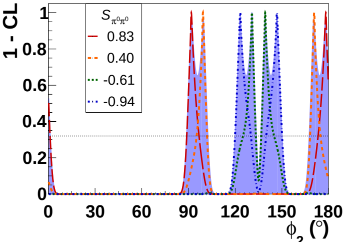
Isospin analysis input in $B \to \pi\pi$

	Value	Belle @ 0.8 ab^{-1}	Belle2 @ 50 ab^{-1}
$\mathcal{B}_{\pi^+\pi^-}$ [10^{-6}]	5.04	$\pm0.21 \pm 0.18$ [2]	$\pm0.03 \pm 0.08$
$\mathcal{B}_{\pi^0\pi^0}$ [10^{-6}]	1.31	$\pm0.19 \pm 0.18$ [1]	$\pm0.04 \pm 0.04$
$\mathcal{B}_{\pi^+\pi^0}$ [10^{-6}]	5.86	$\pm0.26 \pm 0.38$ [2]	$\pm0.03 \pm 0.09$
$C_{\pi^+\pi^-}$	-0.33	$\pm0.06 \pm 0.03$ [3]	$\pm0.01 \pm 0.03$
$S_{\pi^+\pi^-}$	-0.64	$\pm0.08 \pm 0.03$ [3]	$\pm0.01 \pm 0.01$
$C_{\pi^0\pi^0}$	-0.14	$\pm0.36 \pm 0.12$ [1]	$\pm0.03 \pm 0.01$
$S_{\pi^0\pi^0}$	—	—	$\pm0.29 \pm 0.03$



[1]: arXiv:1705.02083
[2]: PRD 87(3) 031103
[2]: PRD 88(9) 092003

Adding $S_{\pi^0\pi^0}$ input $\Longrightarrow$



$\Delta\alpha^{exp}_{\pi\pi}|^{88^\circ}_{1\sigma} \sim 4^\circ$

$\sin(2\alpha)$ measurement: $B \to \rho\rho$

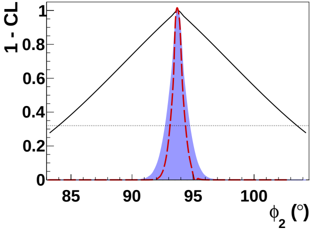
Isospin analysis input in $B \to \rho\rho$

	Value	Belle @ 0.8 ab^{-1}	Belle2 @ 50 ab^{-1}
$f_{L,\rho^+\rho^-}$	0.988	$\pm 0.012 \pm 0.023$ [1]	$\pm 0.002 \pm 0.003$
$f_{L,\rho^0\rho^0}$	0.21	$\pm 0.20 \pm 0.15$ [2]	$\pm 0.03 \pm 0.02$
$\mathcal{B}_{\rho^+\rho^-}$ [10^{-6}]	28.3	$\pm 1.5 \pm 1.5$ [1]	$\pm 0.19 \pm 0.4$
$\mathcal{B}_{\rho^0\rho^0}$ [10^{-6}]	1.02	$\pm 0.30 \pm 0.15$ [2]	$\pm 0.04 \pm 0.02$
$C_{\rho^+\rho^-}$	0.00	$\pm 0.10 \pm 0.06$ [1]	$\pm 0.01 \pm 0.01$
$S_{\rho^+\rho^-}$	-0.13	$\pm 0.15 \pm 0.05$ [1]	$\pm 0.02 \pm 0.01$
	Value	Belle @ 0.08 ab^{-1}	Belle2 @ 50 ab^{-1}
$f_{L,\rho^+\rho^0}$	0.95	$\pm 0.11 \pm 0.02$ [3]	$\pm 0.004 \pm 0.003$
$\mathcal{B}_{\rho^+\rho^0}$ [10^{-6}]	31.7	$\pm 7.1 \pm 5.3$ [3]	$\pm 0.3 \pm 0.5$
	Value	BaBar @ 0.5 ab^{-1}	Belle2 @ 50 ab^{-1}
$C_{\rho^0\rho^0}$	0.2	$\pm 0.8 \pm 0.3$ [4]	$\pm 0.08 \pm 0.01$
$S_{\rho^0\rho^0}$	0.3	$\pm 0.7 \pm 0.2$ [4]	$\pm 0.07 \pm 0.01$

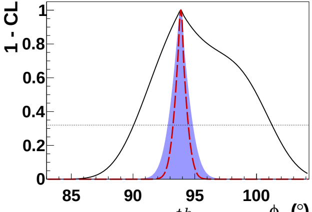
[1]: PRD 93(3) 032010, [2]: Add PRD 89 no.11 119903,
[3]: PRL 91 221801, [4]: PRD 78 071104

Belle, **Belle2** (+ $S_{\rho^0\rho^0}$, $S_{\pi^0\pi^0}$)

$B \to \rho\rho$, $\Delta\alpha^{exp}_{\rho\rho}|_{1\sigma} \sim 0.7^\circ$



$B \to \rho\rho$ & $B \to \pi\pi$
$\Delta\alpha^{exp}_{hh}|_{1\sigma} \sim 0.6^\circ$



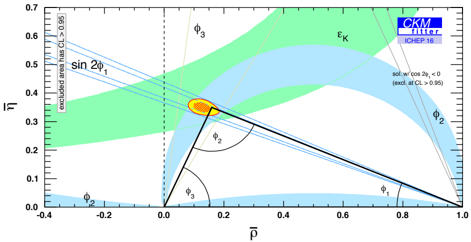
Conclusions

The Belle 2 program

- large dataset ⊕ improved detector and physics software (Flavor tagging, vertex reconstruction)
- unique possibilities for modes with final state with neutral particles

- **sin (2β)** will remain the most precise measurement on the UT parameters (precision level of penguin pollution)
- **sin (2α)** measurement will benefit of reduced errors and new inputs ($S_{\pi^0\pi^0}$, $B \to \rho\pi$ mode) for isospin analysis
- other time dependent CP-violation analysis feasible @ Belle2 (photon polarization in $B^0 \to K^{\star}(\to \pi^0 K_S^0)\gamma$)

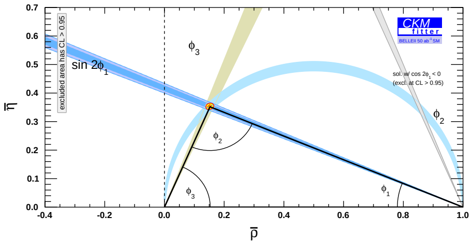
Current world average



CPV only inputs

More details in the Belle II Physics Book

Belle2 projection @ 50ab^{-1}



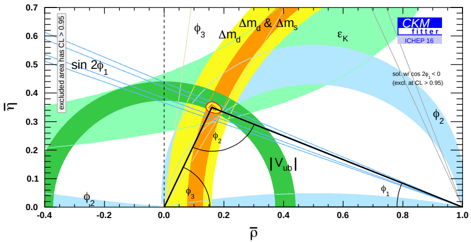
Conclusions

The Belle 2 program

- large dataset ⊕ improved detector and physics software (Flavor tagging, vertex reconstruction)
- unique possibilities for modes with final state with neutral particles

- **sin (2β)** will remain the most precise measurement on the UT parameters (precision level of penguin pollution)
- **sin (2α)** measurement will benefit of reduced errors and new inputs ($S_{\pi^0\pi^0}$, $B \to \rho\pi$ mode) for isospin analysis
- other time dependent CP-violation analysis feasible @ Belle2 (photon polarization in $B^0 \to K^\star(\to \pi^0 K_S^0)\gamma$)

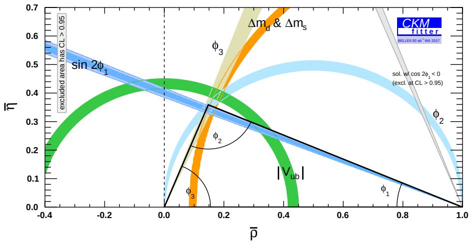
Current world average



All inputs

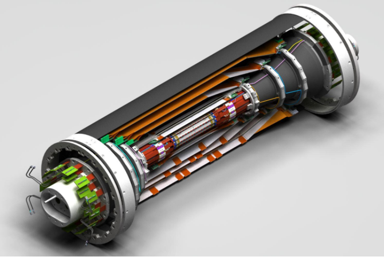
More details in the Belle II Physics Book

Belle2 projection @ 50ab^{-1}

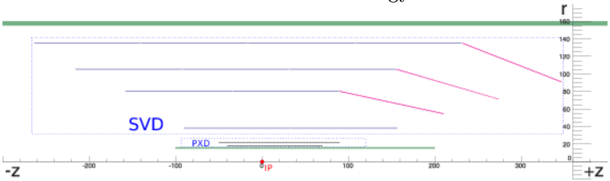


Backup

Belle2 Vertexing



DEPFET Technology

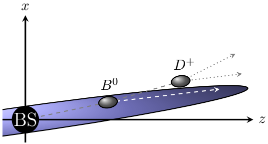


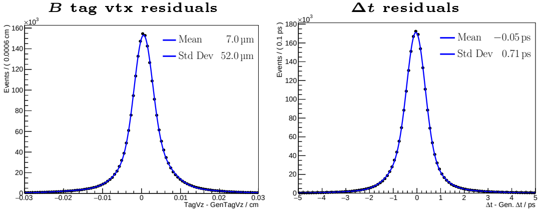
Benchmark modes

$J/\psi \to \mu\mu$ in $B^0 \to J/\psi K_S^0$

$\Delta z \sim 26\mu m$

B tag in $B^0 \to J/\psi K_S^0$





$\sin(2\beta)$ in $b \to c\bar{c}s$ transitions

	No improvement	Vertex improvement	Leptonic categories
$S_{J/\psi K_S^0}$ (50 ab^{-1})			
stat.	0.0035	0.0035	0.0060
syst. reducible	0.0012	0.0012	0.0012
syst. irreducible	0.0082	0.0044	0.0040
$A_{J/\psi K_S^0}$ (50 ab^{-1})			
stat.	0.0025	0.0025	0.0043
syst. reducible	0.0007	0.0007	0.0007
syst. irreducible	$^{+0.043}_{-0.022}$	$^{+0.042}_{-0.011}$	0.011

	No improvement	Vertex improvement	Leptonic categories
$S_{J/\psi \pi^0}$ (50 ab^{-1})			
stat.	0.027	0.027	0.047
syst. reducible	0.009	0.009	0.009
syst. irreducible	0.050	0.025	0.025
$A_{J/\psi \pi^0}$ (50 ab^{-1})			
stat.	0.020	0.020	0.035
syst. reducible	0.004	0.004	0.004
syst. irreducible	0.045	0.042	0.017

	No improvement	Vertex improvement	Leptonic categories
$S_{c\bar{c}s}$ (50 ab^{-1})			
stat.	0.0027	0.0027	0.0048
syst. reducible	0.0026	0.0026	0.0026
syst. irreducible	0.0070	0.0036	0.0035
$A_{c\bar{c}s}$ (50 ab^{-1})			
stat.	0.0019	0.0019	0.0033
syst. reducible	0.0014	0.0014	0.0014
syst. irreducible	0.0106	0.0087	0.0035

Penguin pollution in $\sin(2\beta)$ from $B^0 \to J/\psi K^0_S$

Let us denote the $\mathcal{O}(\lambda^s_u/\lambda^s_c)$ terms in by $\Delta S_{J/\psi K^0_S}$

$$S_{J/\psi K^0_S} \equiv \sin 2\phi_1 + \Delta S_{J/\psi K^0_S} \equiv \sin(2\phi_1 + \delta\phi_{J/\psi K^0_S})$$

$\delta\phi_{J/\psi K^0_S} \sim \mathcal{O}(\lambda^s_u/\lambda^s_c)$. Small parameters $\Delta S_{J/\psi K^0_S}$ or $\delta\phi_{J/\psi K^0_S}$ referred to as the 'penguin pollution' in the extraction of ϕ_1 from $S_{J/\psi K^0_S}$.

Need strategies to either compute, bound or control $\Delta S_{J/\psi K^0_S}$.

$$\Delta S_{J/\psi K^0_S} = 2\bar{\lambda}^2 \mathrm{Re}\frac{P_f}{T_f} \sin\phi_3 \cos 2\phi_1 + \mathcal{O}(\bar{\lambda}^4)$$

Strategy	$\Delta S_{J/\psi K^0_S}$ [%]	$\delta\phi_{J/\psi K^0_S}$ [°]
QCDF/pQCD [1,2]	$\lvert\ \ \rvert \lesssim 0.1$	$(\lvert\ \ \rvert \lesssim 0.1)$
OPE [3]	$(\lvert\ \ \rvert \lesssim 0.9)$	$\lvert\ \ \rvert \lesssim 0.68$
Broken U-spin [4,5]	0 ± 2	(0.0 ± 1.6)
Broken U-spin [6]	$([-5, -0.5])$	$[-2.0, -0.4]$
$SU(3)$ at $\mathcal{O}(\varepsilon)$ [7]	$\lvert\ \ \rvert \lesssim 1$	$\lvert\ \ \rvert \lesssim 0.8$
Broken $SU(3)$ [8]	$(-(1.4^{+0.9}_{-1.1}))$	$-(1.10^{+0.70}_{-0.85})$

[1]: PRD 70 036006, [2]: JHEP 03 009, [3]: PRL 115 061802, [4]: PRL 95 221804, [5]: arXiv:1102.0392, [6]: PRD79 014030, [7]: PRD 86 053008, [8]: JHEP 1503 145

Penguin pollution in $\sin(2\beta)$ from $B^0 \to J/\psi K^0_S$

U-spin-breaking corrections are parametrized by the parameter $\varepsilon \sim m_s/\Lambda_{QCD} \sim 0.2$.

Flavor breaking corrections cannot be controlled with a single partner mode, and hence such U-spin analyses require additional assumptions

$$(1+\bar{\lambda}^2)\sin 2\phi_1 = S_{J/\psi K^0_S} - \bar{\lambda}^2 S_{J/\psi \pi^0} - 2(\Delta_K + \bar{\lambda}^2 \Delta_\pi)\cos 2\phi_1 \, \tan\phi_3$$

where penguin pollution effects are cancelled to $\mathcal{O}(\varepsilon)$ and leading corrections arise from isospin-breaking terms. Here $\Delta_{K,\pi}$ are splittings of the charged and neutral CP-averaged rates,

$$\Delta_K \equiv \frac{\bar{\Gamma}_{B_d \to J/\psi K^0} - \bar{\Gamma}_{B^+ \to J/\psi K^+}}{\bar{\Gamma}_{B_d \to J/\psi K^0} + \bar{\Gamma}_{B^+ \to J/\psi K^+}}$$

$$\Delta_\pi \equiv \frac{2\bar{\Gamma}_{B_d \to J/\psi \pi^0} - \bar{\Gamma}_{B^+ \to J/\psi \pi^+}}{2\bar{\Gamma}_{B_d \to J/\psi \pi^0} + \bar{\Gamma}_{B^+ \to J/\psi \pi^+}}$$

Expected uncertainty of $\sim 0.1^\circ$ on ϕ_1 from $B^0 \to J/\psi K^0_S$, when estimating penguin pollution and ignoring for now the $\mathcal{O}(\epsilon^2)$ effects from SU(3) breaking.

$\sin(2\beta)$ in $b \to c\bar{c}s$ transitions - systematics from Belle

		$J/\psi K_S^0$	$\psi(2S) K_S^0$	$\chi_{c1} K_S^0$	$J/\psi K_L^0$	All
Vertexing	$\mathcal{S}_f$	± 0.008	± 0.031	± 0.025	± 0.011	± 0.007
	$\mathcal{A}_f$	± 0.022	± 0.026	± 0.021	± 0.015	± 0.007
Δt	$\mathcal{S}_f$	± 0.007	± 0.007	± 0.005	± 0.007	± 0.007
resolution	$\mathcal{A}_f$	± 0.004	± 0.003	± 0.004	± 0.003	± 0.001
Tag-side	$\mathcal{S}_f$	± 0.002	± 0.002	± 0.002	± 0.001	± 0.001
interference	$\mathcal{A}_f$	$^{+0.038}_{-0.000}$	$^{+0.038}_{-0.000}$	$^{+0.038}_{-0.000}$	$^{+0.000}_{-0.037}$	± 0.008
Flavor	$\mathcal{S}_f$	± 0.003	± 0.003	± 0.004	± 0.003	± 0.004
tagging	$\mathcal{A}_f$	± 0.003	± 0.003	± 0.003	± 0.003	± 0.003
Possible	$\mathcal{S}_f$	± 0.004	± 0.004	± 0.004	± 0.004	± 0.004
fit bias	$\mathcal{A}_f$	± 0.005	± 0.005	± 0.005	± 0.005	± 0.005
Signal	$\mathcal{S}_f$	± 0.004	± 0.016	< 0.001	± 0.016	± 0.004
fraction	$\mathcal{A}_f$	± 0.002	± 0.006	< 0.001	± 0.006	± 0.002
Background	$\mathcal{S}_f$	< 0.001	± 0.002	± 0.030	± 0.002	± 0.001
Δt PDFs	$\mathcal{A}_f$	< 0.001	< 0.001	± 0.014	< 0.001	< 0.001
Physics	$\mathcal{S}_f$	± 0.001	± 0.001	± 0.001	± 0.001	± 0.001
parameters	$\mathcal{A}_f$	< 0.001	< 0.001	± 0.001	< 0.001	< 0.001
Total	$\mathcal{S}_f$	± 0.013	± 0.036	± 0.040	± 0.021	± 0.012
	$\mathcal{A}_f$	$^{+0.045}_{-0.023}$	$^{+0.047}_{-0.027}$	$^{+0.046}_{-0.026}$	$^{+0.017}_{-0.041}$	± 0.012

Systematic errors in $\mathcal{S}_f$ and $\mathcal{A}_f \equiv \mathcal{C}_f$ in each f_{CP} mode and for the sum of all modes [PRL 108 171802]

$b \to q\bar{q}s$ modes efficiencies

$B^0 \to \eta' K^0$

Channel	Strategy	ε	ε_{SxF}
$\eta'(\eta_{\gamma\gamma}\pi^{\pm})K_S^{(\pm)}$	C⋆	23.0 %	3.8 %
$\eta'(\eta_{3\pi}\pi^{\pm})K_S^{(\pm)}$	A	6.7 %	2.6%
	B⋆	8.0 %	6.0%
	C	9.5 %	28.6%

Selection efficiency ε and fraction of signal cross feed candidates ε_{SxF} for the $\eta'(\eta_{\gamma\gamma}\pi^{\pm})K_S^{(\pm)}$ and $\eta'(\eta_{3\pi}\pi^{\pm})K_S^{(\pm)}$ channels when selecting only one (A), two (B), or all (C) the candidates in the event. The selected strategy is labeled with ⋆.

$B^0 \to \omega K^0$

$\omega(\pi^+\pi^-\pi^0)K_S^0(\pi^{\pm})$

L (ab^{-1})	yield	$\sigma(S)$	$\sigma(A)$
1	334	0.17	0.14
5	1670	0.08	0.06
50	16700	0.024	0.020

Extrapolated sensitivity for the ωK_S^0 mode. The Δt resolution is taken from the $\eta' K_S^0$ study, while we assume a reconstruction efficiency of 21%

$B^0 \to \phi K^0$

Channel	ε_{reco}	Yield	$\sigma(S_{\phi K^0})$	$\sigma(A_{\phi K^0})$
1 ab^{-1} lumi.:				
$\phi(K^+K^-)K_S^0(\pi^+\pi^-)$	35%	456	0.174	0.123
$\phi(K^+K^-)K_S^0(\pi^0\pi^0)$	25%	153	0.295	0.215
$\phi(\pi^+\pi^-\pi^0)K_S^0(\pi^+\pi^-)$	28%	109	0.338	0.252
K_S^0 modes combination			0.135	0.098
$K_S^0 + K_L^0$ modes combination			0.108	0.079
5 ab^{-1} lumi.:				
$\phi(K^+K^-)K_S^0(\pi^+\pi^-)$	35%	2280	0.078	0.055
$\phi(K^+K^-)K_S^0(\pi^0\pi^0)$	25%	765	0.132	0.096
$\phi(\pi^+\pi^-\pi^0)K_S^0(\pi^+\pi^-)$	28%	545	0.151	0.113
K_S^0 modes combination			0.060	0.044
$K_S^0 + K_L^0$ modes combination			0.048	0.035

Sensitivity estimates for $S_{\phi K^0}$ and $A_{\phi K^0}$ parameters. The efficiency ε_{reco} used in this estimate has not been taken from the simulation, but is rather an estimate taking into account the expected improvements. Systematic uncertainties, negligible for these integrated luminosities, are not included

$\sin(2\beta)$ expected sensitivities

Channel	$\int \mathcal{L}$	Event yield	$\sigma(S)$	$\sigma(S)_{2017}$	$\sigma(A)$	$\sigma(A)_{2017}$
$J/\psi K^0$	50 ab^{-1}	$1.4 \cdot 10^6$	0.0052	0.022	0.0050	0.021
ϕK^0	5 ab^{-1}	5590	0.048	0.12	0.035	0.14
$\eta' K^0$	5 ab^{-1}	27200	0.027	0.06	0.020	0.04
ωK^0_S	5 ab^{-1}	1670	0.08	0.21	0.06	0.14
$K^0_S \pi^0 \gamma$	5 ab^{-1}	1400	0.10	0.20	0.07	0.12
$K^0_S \pi^0$	5 ab^{-1}	5699	0.09	0.17	0.06	0.10

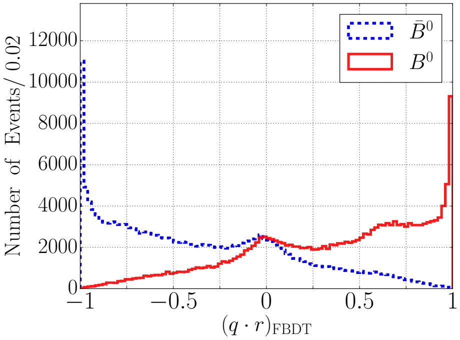
Expected yields and uncertainties on the S and A parameters for the channels sensitive to $\sin(2\phi_1)$ discussed in this chapter for an integrated luminosity of 50 (5) ab^{-1} for $J/\psi K^0$ (penguin dominated modes). In the 5th and the last column are shown the present WA errors on each of the observables (HFAG summer 2016).

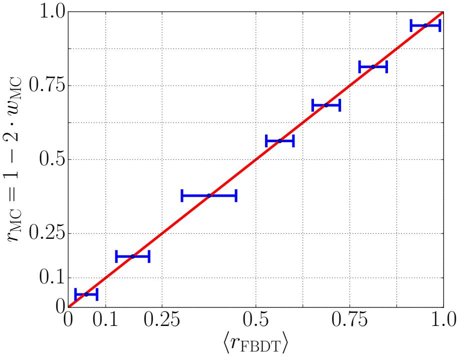
Flavor tagging ε & w

Fast BDT Combiner

r- bin	$\varepsilon_i(\%)$	$\Delta\varepsilon_i(\%)$	$w_i(\%)$	$\Delta w_i(\%)$	$\varepsilon_{\text{eff},i}(\%)$	$\Delta\varepsilon_{\text{eff},i}(\%)$
0.000 – 0.100	12.4	0.0	47.6	0.0	0.0	0.0
0.100 – 0.250	14.4	−0.1	41.4	0.0	0.4	0.0
0.250 – 0.500	21.0	−0.1	31.2	−0.1	3.0	0.0
0.500 – 0.625	11.5	0.3	21.8	0.0	3.7	0.2
0.625 – 0.750	12.0	0.4	15.6	0.1	5.7	0.4
0.750 – 0.875	11.8	−0.1	9.4	0.0	7.8	−0.1
0.875 – 1.000	16.9	−0.6	2.4	0.1	15.3	−1.2
Total	$\varepsilon_{\text{eff}} = \sum_i \varepsilon_i \cdot \langle 1 - 2w_i \rangle^2 = 35.8\%$				$\Delta\varepsilon_{\text{eff}} = -0.7\%$	

Flavor tagging ε & w





$B \to \pi\pi$, $B \to \rho\rho$

$$\chi^2 = -2\log\left[\frac{\exp\left(\frac{1}{2}\left(\mathbf{x}_{\text{data}} - \mathbf{x}_{\text{theo}}\right)^T \Sigma^{-1} \left(\mathbf{x}_{\text{data}} - \mathbf{x}_{\text{theo}}\right)\right)}{\sqrt{(2\pi)^n \det\Sigma}}\right]$$