Prospects for CP violation in inclusive and exclusive B decays at Belle II

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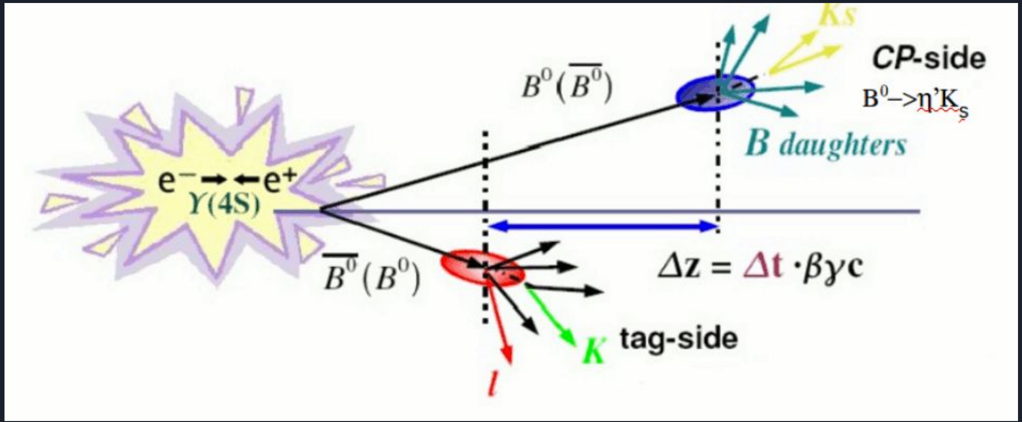
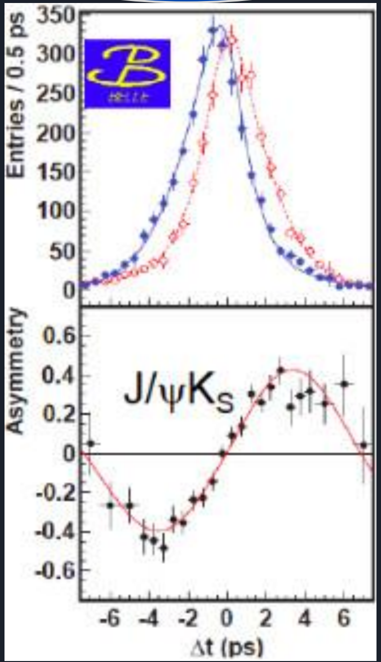
Time-dependant evolution



$(\Delta z)_{Belle}$ ~ 200 μm

$(\Delta z)_{Belle2}$ ~ 130 μm



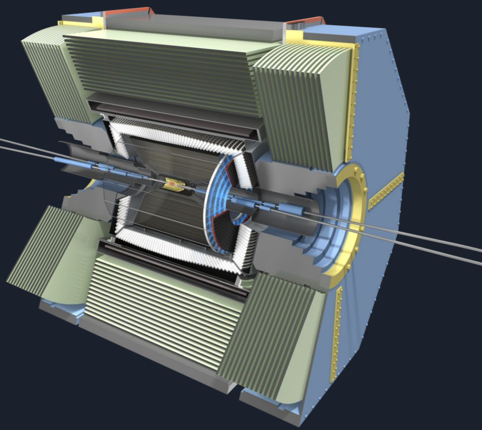
$$a_{f_{CP}}(\Delta t) \equiv \frac{\Gamma[B(\Delta t)] - \Gamma[\bar{B}(\Delta t)]}{\Gamma[B(\Delta t)] + \Gamma[\bar{B}(\Delta t)]} = C\cos(\Delta M \Delta t) - S\sin(\Delta M \Delta t)$$

Direct CPV

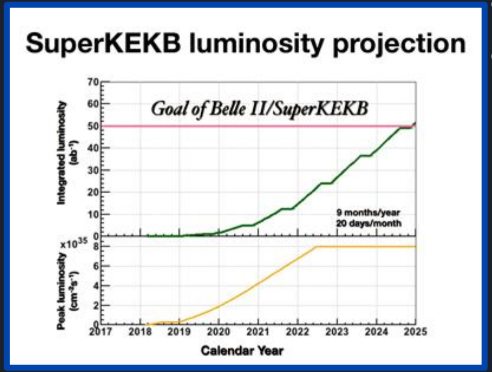
mixing induced CPV

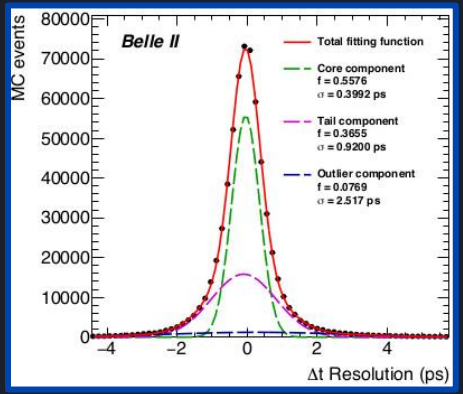
1. Fully reconstructed one of B mesons which decays to CP eigenstates
2. Tag-side determines its flavour (efficiency ≈ 30%)
3. Proper time (Δt) is measured from decay-vertex difference (Δz).

SuperKEKB and Belle II detector



- ★ Reduction in the beam size by 1/20 at the IP
- ★ Doubling the beam current
- ★ $\mathcal{L}\,(10^{34} s^{-1}\, cm^{-2}) = 80$
- ★ $\int \mathcal{L}\, dt\ (ab^{-1}) = 50$
- ★ Factor 2 improvement in vertexing
- ★ Efficient flavour tagger
- ★ Main improvement in performance in two areas:
  - ○ Tracking and vertex determination;
  - ○ Particle ID

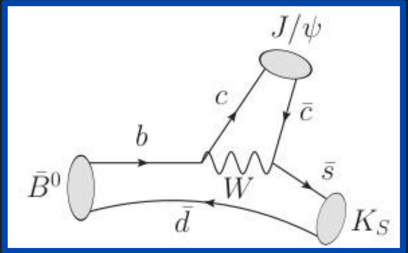




$\beta = \varphi_1$

sin $(2\varphi_1)$ in tree dominated $b \to c\bar{c}s$ transitions

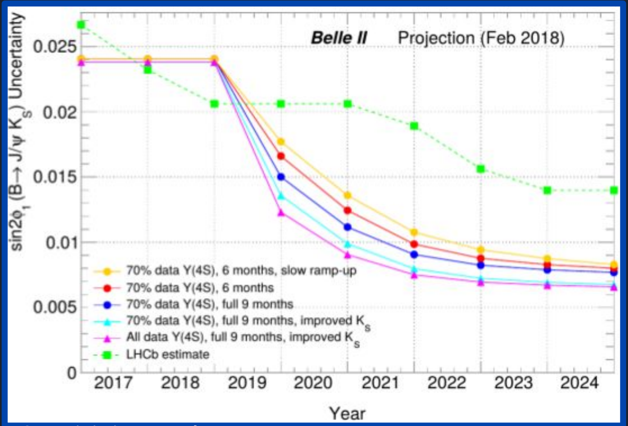
Signal tree diagram



S ~ sin $(2\varphi_1)$

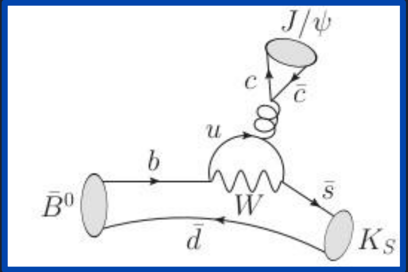
$B^0 \to J/\psi K_s^0$ is the "golden mode" for φ_1

- The expected theoretical uncertainty is small
- Experimental signature is clean ($f = J/\psi K_s^0$ is a CP eigenstate)



Sensitivity study @L.Li Gioi presentation LIO2018

Penguin pollution



Current status from Belle — Belle2 expected uncertainties @ 50 ab^{-1}

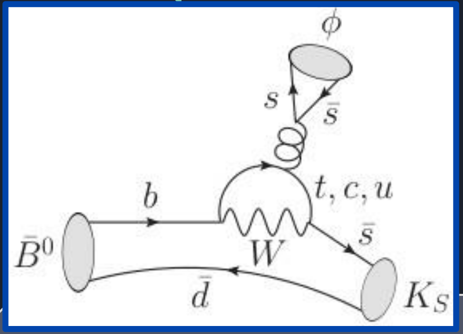
PRL 108 171802	Value	stat(10^{-3})	syst(10^{-3})	stat. BelleII	syst. reduc.	syst1	syst2
$J/\psi K_S^0$ (S)	+0.67	29	13	3.5	1.2	8.2	4.4
$c\bar{c}s$ (S)	+0.667	23	12	2.7	2.6	7.0	3.6

Precision better than 1% is expected on β from b → ccs

$\beta = \varphi_1$

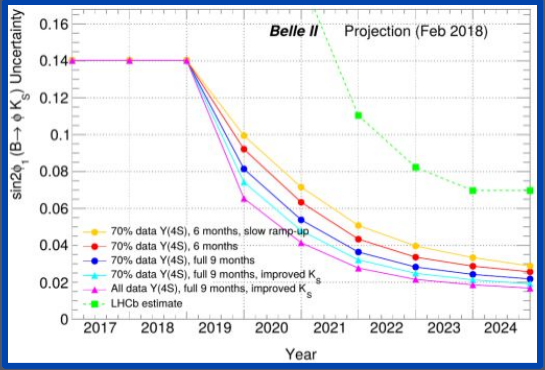
φ_1 from $b \to q\bar{q}s$ transitions:

$B^0 \to \varphi K_s^0$, $B^0 \to \eta' K_s^0$



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

Belle: $S_{\eta' K_s^0} = +0.68 \pm 0.07 \pm 0.03$



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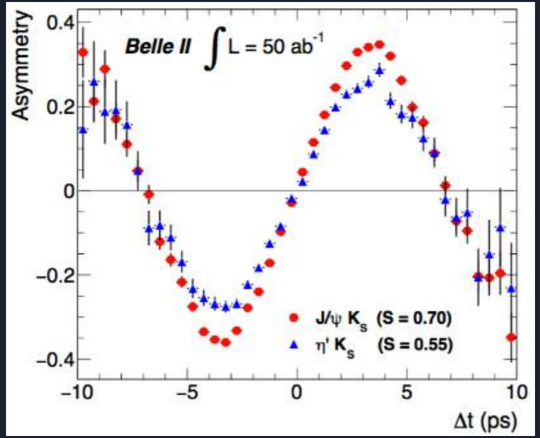
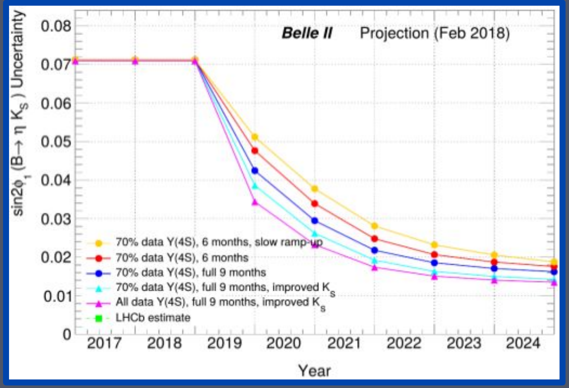


Time dependent CP asymmetries for the final states $J/\psi\, K_S$ (red dots) and $\eta' K_S$ (blue triangles), using $S_{J/\psi\, KS} = 0.70$ and $S_{\eta' Ks} = 0.55$ as inputs to the Monte Carlo



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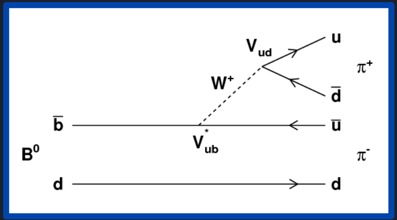
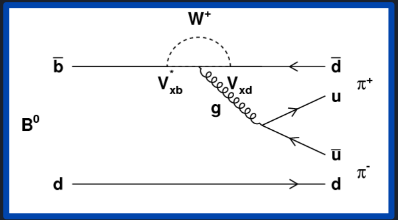
φ_2 measurement in $B \to \pi\pi$; $\rho\rho$

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

$$\varphi_2^{eff} = \varphi_2 + \delta\varphi_2^{peng}$$





C ≠ 0 ⇒ direct CP violation from interference of penguin and tree

Estimation of the penguin contribution exploiting isospin relation:

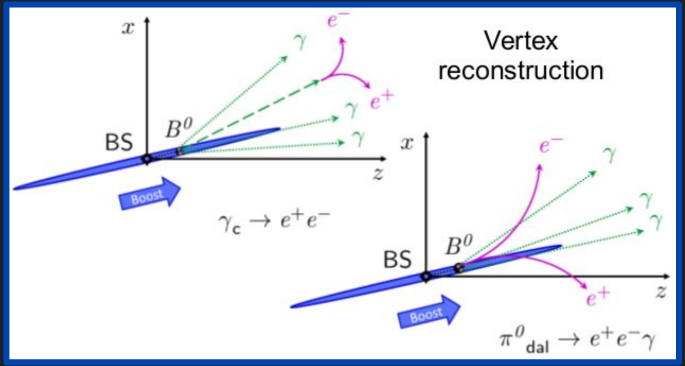
$$A^{(i,j)} \equiv A(B^{i+j} \to h^i h^j)\ (h = \pi, \rho\ /\ i,j = \pm, 0)$$

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

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

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

Reconstruction efficiency is crucial for $B \to \pi^0\pi^0$



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

$\Delta S(\pi^0\pi^0) = \pm\, 0.28 \pm 0.03$

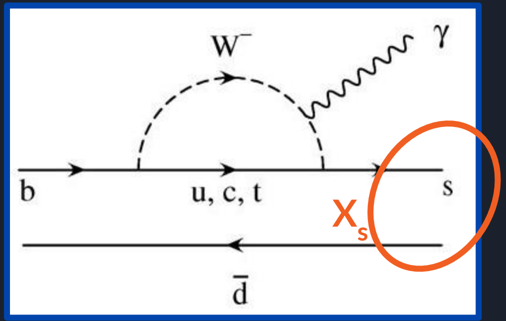
Inclusive B meson decays

$$\alpha_{CP}(B \to X_{s/d}\gamma) = \frac{\Gamma(\bar{B} \to X_{s/d}\gamma) - \Gamma(B \to X_{\bar{s}/\bar{d}}\gamma)}{\Gamma(\bar{B} \to X_{s/d}\gamma) + \Gamma(B \to X_{\bar{s}/\bar{d}}\gamma)}$$

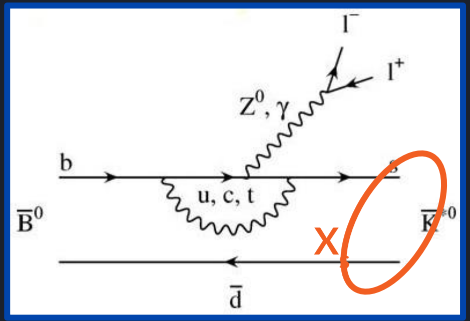
α_{CP} = 0 in SM

In contrast to the exclusive rare B decays, the inclusive ones are theoretically clean observables and dominated by the partonic contributions.

$$\Gamma(B \to X_s\gamma) = \Gamma(b \to X_s^{parton}\gamma) + \Delta^{nonpert.}$$



Radiative penguin



EW penguin

Photon polarization

Standard Model makes definite prediction of photon helicity (D. Atwood et al., Phys. Rev. Lea. 79, 185 (1997)):

- $\bar{B}^0 \to X_s \gamma_R$
- $B^0 \to X_s \gamma_L$

If a helicity flip occurs, the photon will also flip its helicity, producing $B^0 \to X_s \gamma_L$.

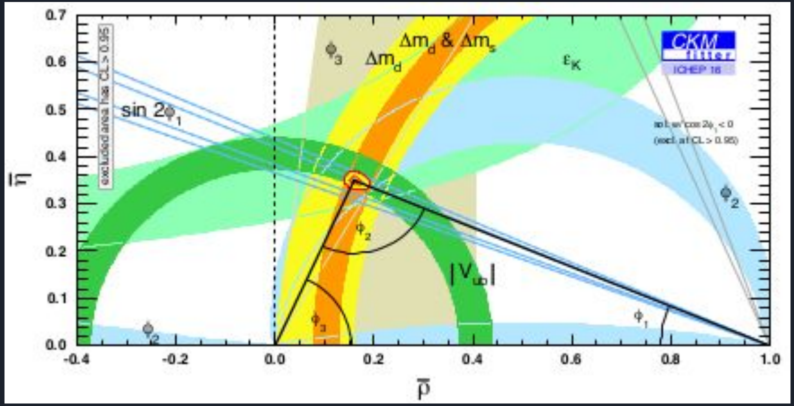
No common final state for B^0 and $\bar{B}^0$

- Suppression of asymmetry S due to interference between B^0 mixing and decay diagrams
- TD CP asymmetry measurements give an indirect measurement of photon polarization.

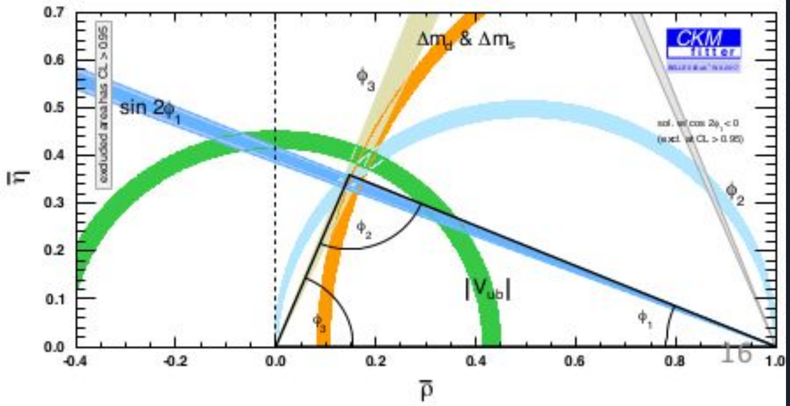
From the theoretical point of view the sum of the CP asymmetries in the inclusive $b \to s$ and $b \to d$ transitions turns out to be the favourable observable. On Belle II will be possible to check it experimentally.

Summary

1. Belle II provides a large dataset + improved detector and physics software (Flavor tagging and Vertex reconstruction).
2. Unique possibilities for modes with final state with neutral particles.
3. sin $(2\varphi_1)$ will remain the most precise measurement on the UT parameters (precision level of penguin pollution).
4. sin $(2\varphi_2)$ measurement will benefit of reduced errors and new inputs for isospin analysis.
5. CP violation can be measured in B decays exclusively and inclusively. Exclusive approach gives up to now the most stringent test of SM.
6. In contrast, the inclusive ones are theoretically clean, usually zero in SM.



Current world average

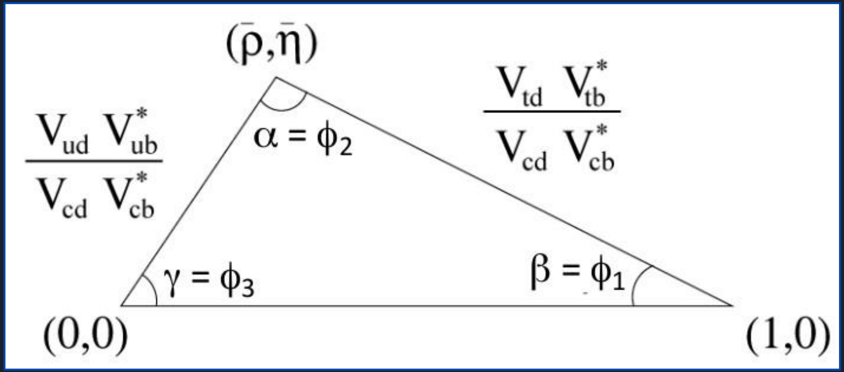


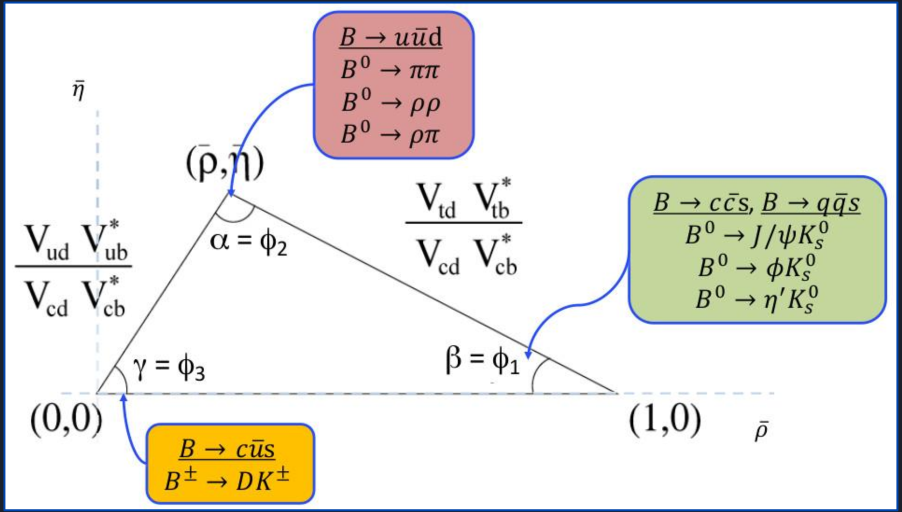
Belle II projection on 50 ab^{-1}

Thank You for Attention

Backup...

B^0 unitarity triangle





Expected sensitivity at 50ab^{-1}

Channel	σ(S)	σ(C)
$\phi(K^+K^-)K^0_S(\pi^+\pi^-)$	0.025	0.017
$\phi(K^+K^-)K^0_S(\pi^0\pi^0)$	0.042	0.030
$\phi(\pi^+\pi^-\pi^0)K^0_S(\pi^+\pi^-)$	0.048	0.036
$K^0_S(\pi^+\pi^-)$ modes	0.019	0.014
$K^0_S(\pi^+\pi^-) + K^0_L(\pi^+\pi^-)$ modes	0.015	0.011

Channel	σ(S)	σ(C)
$\eta'(\eta_{\gamma\gamma}\pi^\pm)K^\pm_S$	0.019	0.013
$\eta'(\eta_{3\pi}\pi^\pm)K^\pm_S$	0.035	0.025
K^0_S modes	0.009	0.007
K^0_L modes	0.025	0.016
$K^0_S + K^0_L$ modes	0.0085	0.0063
Syst. (10^{-2})	1.8 (1.3)	-

Backup

	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]	$\pm 0.07 \pm 0.01$

	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]	$\pm0.03 \pm 0.01$
$S_{\pi^0\pi^0}$	—	—	$\pm0.29 \pm 0.03$