Belle II prospects for CP-violation measurements

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The Unitarity Triangle

- Quark interactions described by the $V_{\text{CKM}}$ unitary matrix
- Unitarity relations represented by triangles in complex plane

\[
V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0
\]

$B \rightarrow u \bar{u} \, d$

\[
\begin{align*}
\alpha &= \phi_2 \\
\gamma &= \phi_3 \\
\beta &= \phi_1
\end{align*}
\]

$(0,0)$ \hspace{1cm} $B \rightarrow c \bar{c} \, s$ \hspace{1cm} $(1,0)$ \hspace{1cm} $B \rightarrow q \bar{q} \, s$

The presence of CP violation in the CKM matrix implies non-trivial values for these angles

Belle II goal → test the SM and search for non SM physics using precision measurements at the intensity frontier through measurements of the triangle parameters
Achievements at B factories

10 successful years:
first generation of asymmetric B factories BaBar and Belle collected about 1.5 ab\(^{-1}\) of data during 1999 – 2010 → significant contribution to the understanding of the flavour dynamics in the Standard Model

- Discovery of CP violation in B meson transitions and confirmation of the CKM description of flavour physics
- Precision measurement of the CKM matrix elements and the angles of the unitarity triangle
- Constraints on various new physics models
- Observation of several new hadronic states
- Strong evidence of D meson mixing
Next generation B factory

SuperKEKB – major upgrade of the KEKB B factory at KEK

\[ e^+e^- \rightarrow BB \text{ mainly at } \sqrt{s_{\text{cm}}} = 10.58 \text{ GeV} \]
\[ (\Upsilon(4S) \text{ resonance}) \]

- Doubled beam currents
- Reduced beam spot size (nano beam scheme)

\[ L_{\text{peak}}: 8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1} \text{ (40 x KEKB)} \]
\[ L_{\text{int}}: 50 \text{ab}^{-1} \text{ by 2025 (50 x KEKB)} \]
From Belle to Belle 2

Many upgrades to increase the performance and cope with more severe background conditions

**Vertex Detector**
- 2 pixel layers
- 4 layers of double-sided silicon microstrip sensors
  → Extended region

**Central drift chamber**
- Small cell size, longer lever arm

**EM calorimeter**
- Upgrade of electronics
- CsI + CsI(Tl) crystals (high light output, short $X_0$)

**$K_L$ and muon detector**
- Some RPCs layers substituted with scintillators
From Belle to Belle 2

Many upgrades to increase the performance and cope with much more severe background conditions

**Vertex Detector**
- 2 pixel layers
- 4 layers of Si double sided
  → Extended VXD region

**Central drift chamber**
- Small cell size, longer lever arm

**EM calorimeter**
- upgrade of electronics
- CsI + CsI(Tl) crystals (high light output, short $X_0$)

**$K_L$ and muon detector**
- some RPCs layers substituted with scintillators

- gain in robustness against beam-related background
- improvement in impact parameter resolution
- 30% increase $K_s$ efficiency
- improved $K/\pi$ separation with $\pi$ fake rate decreases by $\sim 2.5$
- improved $\pi^0$ reconstruction
Phase 1 (Feb - June 2016): beam storage, vacuum scrubbing, optics studies, no collisions
Phase 2 (2018): first collisions, complete Belle II detector except for Vertex Detector
Phase 3 (late 2018 - 2024): full Belle II detector
All plots and performance figures shown today are based on simulation.
Belle II prospects for CP-violation measurements

\[ \varphi_1, \varphi_2(\beta, \alpha) : \text{general strategy} \]

decay time-dependent measurements

Interference between B–B̄ mixing and B decay amplitudes → time-dependent CP asymmetry

Interference between B–B̄ mixing and B decay amplitudes → time-dependent CP asymmetry

\[ a_{fCP}(\Delta t) = \frac{\Gamma[B(\Delta t)] - \Gamma[\overline{B}(\Delta t)]}{\Gamma[B(\Delta t)] + \Gamma[\overline{B}(\Delta t)]} = C \cos(\Delta M \Delta t) + S \sin(\Delta M \Delta t) \]

C = direct CPV

S = \sin(2\phi_{\text{eff}}) \text{mixing induced CPV}

key aspects:

- \( \Delta t \) resolution → vertex fitting

- Flavour tagger

\( \Delta z \sim 130 \mu m \) (Belle II)

\( \Delta z \sim 200 \mu m \) (Belle)

asymmetric energies produce boosted Y(4s), decaying into coherent BB pair

\[ \Delta z \sim 130 \mu m \] (Belle II)

\[ \Delta z \sim 200 \mu m \] (Belle)
Belle II performance: Vertex fit

An improvement in vertex-fit position resolution wrt Belle: compatible with the expected improvement in the impact parameter resolution due to the Belle II Pixel Vertex Detector.

### Simulation-based plots

B$^0 \to J/\psi K^0_s$ decay mode: benchmark for testing the Belle II vertexing performance.

- **Tag side vertex fit**
  - Belle II $\sigma$: 53$\mu$m
  - Belle $\sigma$: 89$\mu$m

- **$\Delta t$ resolution**
  - Belle II $\sigma$: 0.77ps
  - Belle $\sigma$: 0.92ps
Belle II performance: Flavour tagger

- Determine the flavor of the accompanying $B^0$ meson at the time of its decay
- Many $B$ decay channels provide unambiguous flavor signatures through a flavor-specific final state but it is unfeasible to fully reconstruct a large number of flavor-specific $B_{\text{tag}}$ decays.
- Instead of a full reconstruction, the flavor tagger applies inclusive techniques (in semileptonic $B \rightarrow D l \nu$ decays charge of the lepton identifies the flavour of the $B$ meson)

Advanced tagging algorithm is expected to provide high tagging efficiency:

$$\epsilon_{\text{EFF}} = 35.84\% \quad (\epsilon_{\text{EFF}}^{\text{BELLE}} = 30.04\%)$$
**sin(2φ₂): isospin analysis (φ₂ = α)**

φ₂ can be extracted from mixing-induced CP violation in $B \to u\bar{u}d$ transitions

$$S_{CP} = \sqrt{1 - A_{CP}^2 \sin(2(φ₂ + Δφ₂))}$$

= 0 at tree-level
but possible penguin pollution!

The most precise way to determine φ₂ is based on applying the isospin [M. Gronau and D. London, PRL 65 3381] measurement to $B \to ππ$ and $B \to ρρ$

To disentangle the tree contribution and extract $Δφ₂$:

$$\frac{1}{\sqrt{2}} A^{+-} + A^{00} = A^{+0}$$

$$\frac{1}{\sqrt{2}} \bar{A}^{+-} + \bar{A}^{00} = \bar{A}^{-0}$$

$A^{+0} = \bar{A}^{-0}$ (pure tree)

with $\bar{A}^{+-} = A(\bar{B} \to ρ^+ ρ^-)$

currently $φ₂ = (94.2±5)°, (166.4±0.8)°$
\[ \sin(2\phi_2) : B \rightarrow \pi \pi \] 

**Belle II prospects for CP-violation measurements**

- Branching fractions and CP violation parameters are the input parameters of the isospin analysis.
- At present no enough data to perform a time dependent CP-analysis of the decay mode \( B \rightarrow \pi^0\pi^0 \).
- \( S^{\pi^0\pi^0} \) is an important input for isospin analysis → Belle2 opens new possibilities.

Decay modes considered in the \( B \rightarrow \pi^0\pi^0 \):

1. \( B^0_{\text{sig}} \rightarrow \pi^0\gamma(\rightarrow \gamma\gamma) \pi^0\gamma(\rightarrow \gamma\gamma) \),
2. \( B^0_{\text{sig}} \rightarrow \pi^0_{\text{dal}}(\rightarrow e^+e^-\gamma) \pi^0\gamma(\rightarrow \gamma\gamma) \),
3. \( B^0_{\text{sig}} \rightarrow \pi^0_{\gamma\gamma}(\rightarrow \gamma\gamma(\rightarrow e^+e^-)\gamma) \pi^0\gamma(\rightarrow \gamma\gamma) \).

Expected sensitivity at the Belle II integrated luminosity of 50\( \text{ab}^{-1} \) \( \delta \phi_2 = 3^\circ \).

Approximately reconstruction of the B decay vertex for time-dependent CP measurement.
\[
\sin(2\varphi_2): \text{B} \rightarrow \rho\rho \quad (\varphi_2 = \alpha)
\]

The expected uncertainty on \(\varphi_2\) with the combined \(\text{B} \rightarrow \pi\pi\) and \(\text{B} \rightarrow \rho\rho\) is 0.6°.
**Belle II prospects for CP-violation measurements**

The most powerful methods for measuring this angle are based on the interference between $b \to c\bar{u}s$ and $b \to u\bar{c}s$ tree amplitudes with different weak and strong phases in the charged B decays to charm final state: $B^\pm \to DK$.

The tree-level nature of the amplitudes involved in $B \to DK$ allows the theoretically clean extraction of $\phi_3$ — theoretical ambiguity in such measurements is much less 1%

- **Direct CP violation**  
  $\to$ interference between $B^\pm \to DK^\pm$ followed by $D \to f$ and $B^\pm \to \bar{D}K^\pm$ followed by $\bar{D} \to f$.

- **Very challenging**  
  $\to$ CKM and color suppression

There are several methods to measure $\phi_3$ that can be grouped according to the choice of the final state.

**Belle II golden mode**: Dalitz-plot analysis of self-conjugate D decays (GGSZ) [PRD68, 054018 (2003)]

$\phi_3 = (78^{+15}_{-16})^\circ$ Belle measurement  

precision on $\phi_3$ is an order worse than $\phi_1$. Can be improved significantly by experimental advantages alone

$\phi_3 = (76.8^{+5.1}_{-5.7})^\circ$ LHCb measurement

Cracow, 10 Jan 2017
The first sensitivity study of Belle II for $\varphi_3$ applies the GGSZ analysis of $B^{\pm} \rightarrow (K_s^0\pi^+\pi^-)_{DK^{\pm}}$ via Dalitz binning used for model-independent analysis.

- Dalitz plane is divided into a number of diagonally-symmetric bins.
- For each bin numbers of $B^{\pm} \rightarrow D K^{\pm}$ decays are measured.
- $D$ decay strong phases difference between $D$ and $\bar{D}$ decays for each bin of Dalitz plot are essential inputs to interpret the measurements related to $\varphi_3$. (defined on charm-factories, the systematic uncertainty on these measurements will become more significant with future running of both Belle II and LHCb)

Expected uncertainty on $\varphi_3$ versus luminosity (based on toy Monte Carlo studies):

$\delta \varphi_3 = 3^\circ$ at 50 ab$^{-1}$
In Belle measurements using other D decay modes (ADS, GLW techniques) have been performed. Therefore, $\phi_3$ programme at Belle II must at least include all these modes and possibly others to realise its full potential.

The extrapolation with a combination of other D modes

Further improvements are possible as several $B \to DK$ modes have not been exploited in Belle

$\delta \phi_3 = 1.6^\circ$ at 50 ab$^{-1}$

the extrapolation is predicated on there being sufficient BESIII data collected at the $\psi(3770)$, approximately 10 fb$^{-1}$, to determine the strong-phase difference parameters required.

Belle II and LHCb will be in competition in $\phi_3$ sensitivity:

- LHCb will clearly have more precise results in fully-charged final states
- Belle II sensitivity to neutrals will allows to include more D modes

expected sensitivity for LHCb and Belle II experiments
The angle $\phi_1$ can be measured in processes with a tree dominant interaction ($B \to J/\psi K^0_s$) or with penguin quark transitions ($B \to \phi K^0_s, B \to \eta' K^0_s$)

The “golden mode” is $B \to J/\psi K^0_s$. Advantages of this decay channel for $\sin 2\phi_1$ measurement:

- clean signature
- relatively large branching fraction, so a large signal yield is expected
- contribution of penguin diagrams expected to be less than 1%

Belle [PRL 108 171802]

$penguin pollution$

$S_{J/\psi K^0_s} = 0.670 \pm 0.029 \text{(stat)} \pm 0.013 \text{(syst)}$
$C_{J/\psi K^0_s} = -0.015 \pm 0.021 \text{(stat)} \pm 0.045 \text{(syst)}$
$S_{ccs} = 0.667 \pm 0.023 \text{(stat)} \pm 0.012 \text{(syst)}$
$C_{ccs} = 0.006 \pm 0.016 \text{(stat)} \pm 0.012 \text{(syst)}$

Belle II the measurement will be dominated by systematics

2 irreducible systematic errors: 
- tag side interference
- vertex reconstruction

Expected an experimental precision better than 1% on $\phi_1$

currently $\phi_1 = (21.4 \pm 0.8)^\circ$
Complementary determination of $\varphi_1$ through $b \to q\bar{q}s$ ($q = u, d, s$) are dominated by penguin transitions. More sensitive to non SM physics effects.

BaBar [arXiv:1201.5897] and Belle [arXiv:1007.3848] extracted the $B_d \to \phi K^0$ CP asymmetry parameters from time-dependent analysis of the $K^+K^-K^0$ final state:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Current Value</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi K^0$</td>
<td>$-\eta S = 0.74 \pm 0.13$</td>
<td>$-\eta S = 0.74 \pm 0.11$</td>
</tr>
<tr>
<td>$A$</td>
<td>$-0.01 \pm 0.14$</td>
<td>$-0.01 \pm 0.12$</td>
</tr>
</tbody>
</table>

- more complex $\eta'$ decay channel
- larger branching fraction (x10)
- no competition with LHCb expected due to neutrals in the final state

BaBar [arXiv:0809.1174] and Belle [arXiv:1408.5991] collaborations performed the CP-violation analyses for this channel:

$$S_{\eta' K^0_s} = +0.57 \pm 0.08 \pm 0.02 \text{(BaBar)}$$

$$S_{\eta' K^0_s} = +0.68 \pm 0.07 \pm 0.03 \text{(Belle)}$$
Other CKM measurement: $V_{ub}$

The $|V_{ub}|$ parameter can be measured through exclusive and inclusive semileptonic $B$ decays.

The most promising channel for exclusive $|V_{ub}|$ measurements at Belle II is $B \to \pi l \nu$

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2 |V_{ub}|^2}{24\pi^3} p^3 |f_B^\pi(q^2)|^2$$

Form factor through QCD based calculation. Its uncertainty limits the precision on $V_{ub}$ but a factor 5 improvement is expected.

- $B \to X_u l \nu$ rate measurement complicated by $B \to X_c l \nu$ background
- $|V_{ub}|$ is extracted from the differential $B \to X_u l \nu$ rate in various phase space regions
- $|V_{ub}|$ value extracted from the fit to the differential $B \to X_u l \nu$ rates with a fit model defined from simulation.
- Predictions of shapes of these functions depend on the dynamic of the decaying $b$ quark → limiting factor for the inclusive $|V_{ub}|$ determination

CURRENT VALUES:

$|V_{ub}^{\text{excl}}| = (3.67\pm0.09(\text{exp})\pm0.12(\text{theo})) \times 10^{-3}$

$|V_{ub}^{\text{incl}}| = (4.52\pm0.15(\text{exp})+0.11(\text{theo})) \times 10^{-3}$

3 standard deviation discrepancy
Belle II prospects for CP-violation measurements

The most promising channel for exclusive $|V_{ub}|$ measurements at Belle II is $B \rightarrow \pi \nu$

**"Hadronic Tagged" measurement**
- Exact momentum of companion B gives good $q^2$ resolution
- $\epsilon = 0.55\%$ ($0.3\%$@Belle)
- Improvement w.r.t. Belle is due to the better tagging algorithms

**"Untagged" measurement**
- Indirect determination of companion B momentum spoils $q^2$ resolution.
- $\epsilon = 20\%$ ($11\%$@Belle)
- Improvement w.r.t. Belle is due to the better ROE handling

Forecast of $|V_{ub}|$ sensitivity in $B \rightarrow \pi \nu$
- Expected precision from $B \rightarrow \pi \nu$
  - (untagged) = 1.7%
  - (tagged) = 1.3%
Belle II prospects for CP-violation measurements

Events with one fully reconstructed tag-side B meson candidate and at least one lepton track for signal candidate are selected.

To improve $|V_{ub}|$ precision Belle II will exploit model-independent parametrisation of shape function.

[arXiv:0807.1926]

Such parametrisation includes $B \to X_S \gamma$ data (as the dynamic of the $b$ quark in such process coincides with that for the $B \to X_u \ell \nu$ at leading order)

Factor 2 improvement: expected precision of inclusive $|V_{ub}|$ at 5(50) ab$^{-1}$ is 3.4(3)\%.
**Summary**

- Major upgrade at KEK for the next generation B-factory
- Large dataset and improved detector

**CKM mechanism will be tested at 1% level**
- \( \sin(2\varphi_1) \): precision better than 1\% on \( \varphi_1 \) using \( \text{ccs} \) modes
- \( \sin(2\varphi_2) \): new inputs for the isospin analysis.

Expected sensitivity \( \delta\varphi_2 = 3^\circ \) at 50 \( \text{ab}^{-1} \)

Most likely, the most relevant contribution using CKM physics to probe NP offered by Belle II will be a significant improvement in the determination of \( \varphi_3 \) and \( |V_{ub}| \):
- \( \varphi_3 \): from \( B \to DK \) decays \( \delta\varphi_3 = 1.6^\circ \) at 50 \( \text{ab}^{-1} \)
- \( |V_{ub}| \): from exclusive (inclusive) semileptonic measurements expected precision of 1.3\%(3\%)
Backup
# Detector components

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Name</th>
<th>Component</th>
<th>Configuration</th>
<th>Readout</th>
<th>$\theta$ coverage</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam pipe</td>
<td>Beryllium</td>
<td>Cylindrical, inner radius 10 mm, 12 $\mu$m  Au (check), 0.6 mm Be, 1 mm paraffin, 0.4 mm Be</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tracking</td>
<td>PXD</td>
<td>Silicon (DEPFET)</td>
<td>Pixel: Sensor size: 15x(11, 136, 170) mm$^2$, Pixel size: 50x(11a 50, 11b 60, 12a 75, 12b 85) $\mu$m$^2$, Two layers at radii: 8, 12 mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SVD</td>
<td>Silicon Strip</td>
<td>Rectangular and trapezoidal, Strip pitch: 50(p)/160(n) - 75(p)/240(n) $\mu$m, Four layers at radii: 38, 80, 104, 135 mm small cell, large cell</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDC</td>
<td>Drift Chamber</td>
<td>14k</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calorimetry</td>
<td>ECL</td>
<td>Si(Ti)</td>
<td>Barrel: $r = 125 - 162$cm, end-cap: $z = -102 - +196$cm 6624 (Barrel), 1152 (FWD), 960 (BWD)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Particle ID</td>
<td>TOP</td>
<td>RICH with quartz radiator</td>
<td>16 segments in $\phi$ at $r \sim 120$ cm, 275 cm long, 2cm thick quartz bars with 4x4 channel MCP PMTs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ARICH</td>
<td>RICH with aerogel radiator</td>
<td>2x2 cm thick focusing radiator with different $n$, HAPD photodetectors FWD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muon ID</td>
<td>KLM</td>
<td>barrel:RPCs and scintillator strips</td>
<td>2 layers with scintillator strips and 12 layers with 2 RPCs 16k, $\phi$ 16k</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>KLM</td>
<td>end-cap: scintillator strips</td>
<td>14 layers of (7-10)x40 mm$^2$ strips 17k</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trigger</td>
<td></td>
<td></td>
<td>Table 2.1: Summary of the detector components.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cracow, 10 Jan 2017

Belle II prospects for CP-violation measurements
**Prospects**

<table>
<thead>
<tr>
<th>Observables</th>
<th>Expected th. accuracy</th>
<th>Expected exp. uncertainty</th>
<th>Facility (2025)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UT angles &amp; sides</td>
<td>***</td>
<td>0.4</td>
<td>Belle II</td>
</tr>
<tr>
<td>$\phi_1$ [°]</td>
<td>**</td>
<td>1.0</td>
<td>Belle II</td>
</tr>
<tr>
<td>$\phi_2$ [°]</td>
<td>**</td>
<td>1.0</td>
<td>Belle II</td>
</tr>
<tr>
<td>$\phi_3$ [°]</td>
<td>**</td>
<td>1.0</td>
<td>Belle II/LHCb</td>
</tr>
<tr>
<td>$V_{ub}$ incl.</td>
<td>***</td>
<td>1%</td>
<td>Belle II</td>
</tr>
<tr>
<td>$V_{ub}$ excl.</td>
<td>**</td>
<td>1.5%</td>
<td>Belle II</td>
</tr>
<tr>
<td>$V_{cb}$ incl.</td>
<td>**</td>
<td>2%</td>
<td>Belle II</td>
</tr>
<tr>
<td>$V_{cb}$ excl.</td>
<td>**</td>
<td>2%</td>
<td>Belle II/LHCb</td>
</tr>
</tbody>
</table>

**CPV**

| $S(B \to \phi K^0)$ | *** | 0.02 | Belle II |
| $S(B \to \eta' K^0)$ | *** | 0.01 | Belle II |
| $A(B \to K^0\pi^+)$ | *** | 4.0  | Belle II |
| $A(B \to K^+\pi^-)$ | *** | 0.20 | LHCB/Belle II |

| (Semi-)leptonic | ** | 3% | Belle II |
| $B(B \to \tau\nu)$ | ** | 7% | Belle II |
| $B(B \to \mu\nu)$ | ** | 7% | Belle II |
| $R(B \to D\tau\nu)$ | ** | 3% | Belle II |
| $R(B \to D^*\tau\nu)$ | ** | 2% | Belle II/LHCb |

**Radiative & EW Penguins**

| $B(B \to X_{s}\gamma)$ | ** | 4% | Belle II |
| $A_{CP}(B \to X_{s}\gamma\gamma)$ | *** | 0.005 | Belle II |
| $S(B \to K^0\pi^0\gamma)$ | *** | 0.03 | Belle II |
| $S(B \to \rho\gamma)$ | *** | 0.07 | Belle II |
| $B(B \to \gamma\gamma)$ | *** | 0.3 | Belle II |
| $B(B \to K^0\nu\bar{\nu})$ | *** | 15% | Belle II |
| $B(B \to K^0\nu\bar{\nu})$ | *** | 20% | Belle II/LHCb |
| $R(B \to K^*\pi\bar{\nu})$ | ** | 0.03 | Belle II/LHCb |

**Charm Rare**

| $B(D_s \to \mu\nu)$ | $5.31 \times 10^{-3}(1.3\pm3.8\%)$ | 2.9% | 0.9% |
| $B(D_s \to \tau\nu)$ | $5.70 \times 10^{-3}(1.3\pm3.7\%)$ | 3.5% | 2.3% |

**Charm CP**

| $A_{CP}(D^0 \to K^+K^-)$ | $-32 \pm 21 \pm 9$ | 11 | 6 |
| $\Delta A_{CP}(D^0 \to K^+K^-)$ | $3.4\%$ | 0.5 | 0.1 |
| $A_{T}$ | $0.22$ | 0.1 | 0.03 |
| $A_{CP}(D^0 \to \pi^0\pi^0)$ | $-0.03 \pm 0.64 \pm 0.10$ | 0.29 | 0.09 |
| $A_{CP}(D^0 \to K^0\bar{K}^0)$ | $-0.21 \pm 0.16 \pm 0.09$ | 0.08 | 0.03 |

**Charm Mixing**

| $x(D^0 \to K^0\pi^+\pi^-)$ | $0.56 \pm 0.19 \pm 0.07$ | 0.14 | 0.11 |
| $y(D^0 \to K^0\pi^+\pi^-)$ | $0.30 \pm 0.15 \pm 0.05$ | 0.08 | 0.05 |
| $|\langle p|/Q(D^0 \to K^0\pi^+\pi^-)|\rangle$ | $0.90 \pm 0.16 \pm 0.06$ | 0.10 | 0.07 |
| $\phi(D^0 \to K^0\pi^+\pi^-)$ | $-6 \pm 11 \pm 4$ | 6 | 4 |

**Tau**

| $\tau \to \mu\nu\bar{\nu}$ | $< 45$ | $< 14.7 < 4.7$ |
| $\tau \to e\gamma$ | $< 120$ | $< 39 < 12$ |
| $\tau \to \mu\mu\mu$ | $< 21.0$ | $< 3.0 < 0.3$ |
### SuperKEKB upgrade

<table>
<thead>
<tr>
<th>Parameter</th>
<th>KEKB</th>
<th>SuperKEKB</th>
</tr>
</thead>
<tbody>
<tr>
<td>LER / HER</td>
<td>3.5 / 8</td>
<td>4.0 / 7.0</td>
</tr>
<tr>
<td>Energy [GeV]</td>
<td>3.5 / 8</td>
<td>4.0 / 7.0</td>
</tr>
<tr>
<td>$\beta_y^*$ [mm]</td>
<td>5.9 / 5.9</td>
<td>0.27 / 0.30</td>
</tr>
<tr>
<td>$\beta_x^*$ [mm]</td>
<td>1200</td>
<td>32 / 25</td>
</tr>
<tr>
<td>$l_{\pm}$ [A]</td>
<td>1.64 / 1.19</td>
<td>3.6 / 2.6</td>
</tr>
<tr>
<td>$\zeta_{\pm y}$</td>
<td>0.129 / 0.09</td>
<td>0.09 / 0.09</td>
</tr>
<tr>
<td>$\epsilon$ [nm]</td>
<td>18 / 24</td>
<td>3.2 / 4.6</td>
</tr>
<tr>
<td># of bunches</td>
<td>1584</td>
<td>2500</td>
</tr>
<tr>
<td>Luminosity $[10^{34} \text{ cm}^2 \text{ s}^{-1}]$</td>
<td>2.1</td>
<td>80</td>
</tr>
</tbody>
</table>
Belle II detector
\[ \sin(2\varphi_1) \text{ from } b \to q\bar{q}s: \, B \to \phi \, K^0_s \]

Complementary determination of \( \varphi_1 \) through \( b \to q\bar{q}s \) (\( q = u, d, s \)) are dominated by penguin transitions. More sensitive to non SM physics effects.

BaBar [arXiv:1201.5897] and Belle [arXiv:1007.3848] extracted the \( B_d \to \phi K^0 \) CP asymmetry parameters from time-dependent analysis of the \( K^+K^-K^0 \) final state:

<table>
<thead>
<tr>
<th>( \phi K^0 )</th>
<th>current value</th>
<th>average</th>
</tr>
</thead>
<tbody>
<tr>
<td>(-\eta S)</td>
<td>0.74</td>
<td>+0.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-0.13</td>
</tr>
<tr>
<td>( A )</td>
<td>-0.01</td>
<td>±0.14</td>
</tr>
</tbody>
</table>

Sensitivity estimates for \( S_{\phi K^0} \) and \( A_{\phi K^0} \) parameters for 1 ab\(^{-1}\) and 5 ab\(^{-1}\):
Bellé II prospects for CP-violation measurements

\[ \sin(2\varphi_1) \text{ from } b \rightarrow q\bar{q}s: \ B \rightarrow \eta' K^0_s \]

Differences with respect \( B_d \rightarrow \phi K^0: \)

- more complex \( \eta' \) decay channel
- larger branching fraction (x10)
- no competition with LHCb expected due to neutrals in the final state

BaBar [arXiv:0809.1174] and Belle [arXiv:1408.5991] collaborations performed the CP-violation analyses for this channel:

- \( S_{\eta'K^0_S} = +0.57 \pm 0.08 \pm 0.02 \) (BaBar)
- \( S_{\eta'K^0_S} = +0.68 \pm 0.07 \pm 0.03 \) (Belle)

Estimated resolution

<table>
<thead>
<tr>
<th>Channel</th>
<th>yield 1 ab(^{-1})</th>
<th>( \sigma(S) )</th>
<th>( \sigma(C) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \eta(2\gamma)K^0_S(\pi^\pm) )</td>
<td>969</td>
<td>0.13</td>
<td>0.08</td>
</tr>
<tr>
<td>( \eta(2\gamma)K^0_S(2\pi^0) )</td>
<td>215</td>
<td>0.27</td>
<td>0.17</td>
</tr>
<tr>
<td>( \eta(3\pi)K^0_S(\pi^\pm) )</td>
<td>283</td>
<td>0.25</td>
<td>0.16</td>
</tr>
<tr>
<td>( \rho(\pi^\pm)K^0_S(\pi^\pm) )</td>
<td>2100</td>
<td>0.06</td>
<td>0.07</td>
</tr>
<tr>
<td>( \rho(\pi^\pm)K^0_S(2\pi^0) )</td>
<td>320</td>
<td>0.10</td>
<td>0.17</td>
</tr>
<tr>
<td>( K_S ) modes</td>
<td>3891</td>
<td>0.065</td>
<td>0.040</td>
</tr>
<tr>
<td>( K_L ) modes</td>
<td>1546</td>
<td>0.17</td>
<td>0.11</td>
</tr>
<tr>
<td>( K_S + K_L ) modes</td>
<td>5437</td>
<td>0.060</td>
<td>0.038</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Channel</th>
<th>yield 5 ab(^{-1})</th>
<th>( \sigma(S) )</th>
<th>( \sigma(C) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \eta(2\gamma)K^0_S(\pi^\pm) )</td>
<td>4840</td>
<td>0.06</td>
<td>0.04</td>
</tr>
<tr>
<td>( \eta(2\gamma)K^0_S(2\pi^0) )</td>
<td>1070</td>
<td>0.12</td>
<td>0.09</td>
</tr>
<tr>
<td>( \eta(3\pi)K^0_S(\pi^\pm) )</td>
<td>1415</td>
<td>0.11</td>
<td>0.08</td>
</tr>
<tr>
<td>( \rho(\pi^\pm)K^0_S(\pi^\pm) )</td>
<td>10500</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>( \rho(\pi^\pm)K^0_S(2\pi^0) )</td>
<td>1600</td>
<td>0.10</td>
<td>0.07</td>
</tr>
<tr>
<td>( K_S ) modes</td>
<td>19500</td>
<td>0.028</td>
<td>0.021</td>
</tr>
<tr>
<td>( K_L ) modes</td>
<td>7730</td>
<td>0.08</td>
<td>0.05</td>
</tr>
<tr>
<td>( K_S + K_L ) modes</td>
<td>27200</td>
<td>0.027</td>
<td>0.020</td>
</tr>
</tbody>
</table>
$\sin(2\varphi_2): B \to \rho\rho$

Branching fractions, fractions of longitudinally polarised events and CP asymmetry parameters entering in the isospin analysis of the $B \to \rho\rho$ system

\begin{array}{c|c|c|c|c|c|c|c}
\hline
 & \text{BELLE} & \text{BELLE II} \\
\hline
f_{L,\rho^+\rho^-} & 0.988 & \pm 0.012 \pm 0.023 \text{ [1]} & \pm 0.002 \pm 0.003 \\
f_{L,\rho^0\rho^0} & 0.21 & \pm 0.20 \pm 0.15 \text{ [2]} & \pm 0.03 \pm 0.02 \\
B_{\rho^+\rho^-} \times 10^{-6} & 28.3 & \pm 1.5 \pm 1.5 \text{ [1]} & \pm 0.19 \pm 0.4 \\
B_{\rho^0\rho^0} \times 10^{-6} & 1.02 & \pm 0.30 \pm 0.15 \text{ [2]} & \pm 0.04 \pm 0.02 \\
C_{\rho^+\rho^-} & 0.00 & \pm 0.10 \pm 0.06 \text{ [1]} & \pm 0.01 \pm 0.01 \\
S_{\rho^+\rho^-} & -0.13 & \pm 0.15 \pm 0.05 \text{ [1]} & \pm 0.02 \pm 0.01 \\
\hline
f_{L,\rho^+\rho^0} & 0.95 & \pm 0.11 \pm 0.02 \text{ [3]} & \pm 0.004 \pm 0.003 \\
B_{\rho^+\rho^0} \times 10^{-6} & 31.7 & \pm 7.1 \pm 5.3 \text{ [3]} & \pm 0.3 \pm 0.5 \\
\hline
C_{\rho^0\rho^0} & 0.2 & \pm 0.8 \pm 0.3 \text{ [4]} & \pm 0.08 \pm 0.01 \\
S_{\rho^0\rho^0} & 0.3 & \pm 0.7 \pm 0.2 \text{ [4]} & \pm 0.07 \pm 0.01 \\
\hline
\end{array}

\[\text{Values: PRD 93(3) 032010, [2]: Add PRD 89 no.11 119903, [3]: PRL 91 221801, [4]: PRD 78 071104}\]
\[ \sin(2\varphi_1) \text{ from } b \rightarrow c\bar{c}s: \text{projections} \]

Belle II the measurement will be dominated by systematics

Three different scenarios:

- "Belle": Belle irreducible systematic uncertainties are assumed to not improve in Belle II (not realistic)
- "Belle II": improvement of 50\% is assumed for the systematic due to the vertex positions
- "Leptonic categories": analysis is performed using only the leptonic categories for flavour tagging

\[
\begin{array}{lcccc}
& \text{Belle} & \text{Belle II} & \text{leptonic categories} \\
\hline
\text{S (50 ab}^{-1}) & 0.0035 & 0.0035 & 0.0060 \\
\text{stat.} & 0.0012 & 0.0012 & 0.0012 \\
\text{syst. reducible} & 0.0082 & 0.0044 & 0.0040 \\
\text{syst. irreducible} & 0.0025 & 0.0025 & 0.0043 \\
\text{A (50 ab}^{-1}) & \text{stat.} & 0.0007 & 0.0007 & 0.0007 \\
\text{syst. reducible} & +0.043 & +0.042 & 0.011 \\
\text{syst. irreducible} & -0.022 & -0.011 & 0.011 \\
\hline
\end{array}
\]

\[
\begin{array}{lcccc}
& \text{Belle} & \text{Belle II} & \text{leptonic categories} \\
\hline
\text{S (50 ab}^{-1}) & 0.0027 & 0.0027 & 0.0048 \\
\text{stat.} & 0.0026 & 0.0026 & 0.0026 \\
\text{syst. reducible} & 0.0070 & 0.0036 & 0.0035 \\
\text{syst. irreducible} & 0.0106 & 0.0087 & 0.0035 \\
\hline
\end{array}
\]

Expected an experimental precision better than 1\% on \[ \varphi_1 \]
$\sin(2\varphi_2): B \rightarrow \pi \pi \quad (\varphi_2 = \alpha)$

- A scan of the confidence for $\varphi_2$ from a $\chi^2$ distribution which is obtained by minimising $2 \log(L)$ is performed. The likelihood $L$ has the form of a multivariate normal distribution:

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

where $x_{\text{data}}$ and $x_{\text{theo}}$ are vectors containing respectively the measured values and the theoretical prediction of parameters $B_+$, $B_{00}$, $B_{+0}$, $C_+$, $S_+$, $C_{00}$ and $S_{00}$.

The covariance matrix $\Sigma$ contains the uncertainties in the diagonal and the correlations between the measured parameters in the non-diagonal part.
expected sensitivity for LHCb and Belle II experiments

For Belle II, we base the projections on a combination of $B \rightarrow DK$ measurements (already performed at Belle), where the $D$ meson decays to:

- $D \rightarrow KK, D \rightarrow \pi \pi, D \rightarrow K \pi$
- $D \rightarrow K \pi \pi \pi$
- $D \rightarrow K_S \pi \pi$

where the combined precision on $\phi_3$ for Belle is taken from CKMFitter.

The LHCb value is based on an extrapolation of the 2015 Run-1 results in LHCb-PAPER-2014-041 and also analysed by CKMFitter. The results are based on a combination of measurements from $B^+ \rightarrow D h^+$ and $B^0 \rightarrow D K^*0$ decays, where $h^+$ corresponds to either $K^+$ or $\pi^+$ and the $D$ meson decays into:

- $D \rightarrow KK, D \rightarrow \pi \pi, D \rightarrow K \pi$
- $D \rightarrow K \pi \pi \pi$
- $D \rightarrow K_S \pi \pi$
Table 95: Expected uncertainties on the $S$ and $A$ parameters for the channels sensitive to sin$(2\varphi_1)$ discussed in this chapter for an integrated luminosity of 5 and 50 ab$^{-1}$. The present (2017) World Average [601] errors are also reported.

<table>
<thead>
<tr>
<th>Channel</th>
<th>$\sigma(S)$</th>
<th>$\sigma(A)$</th>
<th>$\sigma(S)$</th>
<th>$\sigma(A)$</th>
<th>$\sigma(S)$</th>
<th>$\sigma(A)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$J/\psi K^0$</td>
<td>0.022</td>
<td>0.021</td>
<td>0.012</td>
<td>0.011</td>
<td>0.0052</td>
<td>0.0090</td>
</tr>
<tr>
<td>$\phi K^0$</td>
<td>0.12</td>
<td>0.14</td>
<td>0.048</td>
<td>0.035</td>
<td>0.020</td>
<td>0.011</td>
</tr>
<tr>
<td>$\eta' K^0$</td>
<td>0.06</td>
<td>0.04</td>
<td>0.032</td>
<td>0.020</td>
<td>0.015</td>
<td>0.008</td>
</tr>
<tr>
<td>$\omega K^0_S$</td>
<td>0.21</td>
<td>0.14</td>
<td>0.08</td>
<td>0.06</td>
<td>0.024</td>
<td>0.020</td>
</tr>
<tr>
<td>$K^0_S \pi^0 \gamma$</td>
<td>0.20</td>
<td>0.12</td>
<td>0.10</td>
<td>0.07</td>
<td>0.031</td>
<td>0.021</td>
</tr>
<tr>
<td>$K^0_S \pi^0$</td>
<td>0.17</td>
<td>0.10</td>
<td>0.09</td>
<td>0.06</td>
<td>0.028</td>
<td>0.018</td>
</tr>
</tbody>
</table>

$(\varphi_1 = \beta)$