CP Violation sensitivity at the Belle II Experiment

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29th Rencontres de Blois – May 30th 2017
The Unitarity Triangle

- All flavor variables constrained in the SM CKM fit are in good agreement with experimental observations.
- Some variables still to be measured precisely, therefore a lot of room for surprises!

\[
V \approx \begin{pmatrix}
1 & \lambda & \lambda^3 \\
-\lambda & 1 & \lambda^2 \\
-\lambda^3 & -\lambda^2 & 1
\end{pmatrix}
\]

\(\lambda \approx 0.22\): Cabibbo angle

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Time dependent measurements

- $Y(4S)$ is the first resonance just above the $B\bar{B}$ production threshold
- Only $B\bar{B}$ pairs are produced, and are at rest in the $Y(4S)$ frame

\[ \Delta t = \frac{\Delta z}{\beta \gamma c} \]

Resolution on $\Delta t$ will be dominated by the resolution of the tagging side vertex

$\Delta t$ probability parametrization

\[ P(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_B}}{4\tau_B} \left[ 1 + q \left( A_{CP} \cos \Delta m_d \Delta t + S_{CP} \sin \Delta m_d \Delta t \right) \right] \]
\[ \sin(2\beta) : b \rightarrow c \bar{c}s \]
SuperKEKB

Peak luminosity
- KEKB = \(2.11 \times 10^{34}\) cm\(^{-2}\) s\(^{-1}\)
- SuperKEKB = \(8 \times 10^{35}\) cm\(^{-2}\) s\(^{-1}\)

e\(^{+}\)e\(^{-}\) beams energy
- KEKB = 8 GeV / 3.5 GeV
- SuperKEKB = 7 GeV / 4 GeV
Belle II Pixel Vertex Detector

- 40 times increase of luminosity → higher background
- Lower boost → smaller separation between the B mesons

Pixel detector needed

Most suited technology: DEPFET

- Innermost detector system as close as possible to IP
- Highly granular pixel sensors provide most accurate 2D position information

Reconstruction of primary and secondary vertices of short-lived particles
  - Decay of particles is typical in the order of 100μm from the IP
**Vertex fit**

**Tag side vertex fit:** Using RAVE Adaptive Vertex Fit (AVF) algorithm:


### Kinematic fit: $J/\psi \rightarrow \mu \mu$

- **Belle II**
  - Bias = 2.0 $\mu$m
  - Resolution = 25.6 $\mu$m

- **Belle converted MC**
  - Bias = 0.2 $\mu$m
  - Resolution = 43 $\mu$m

### $\Delta t$ resolution

- **Belle II**
  - Bias = -0.003 ps
  - Resolution = 0.77 ps

- **Belle**
  - Bias = 0.20 ps
  - Resolution = 0.92 ps

---

**Tag side vertex fit**

- **Belle II**
  - Bias = 5.9 $\mu$m
  - Resolution = 53 $\mu$m

- **Belle**
  - Bias = 29 $\mu$m
  - Resolution = 89 $\mu$m

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Flavor tagging

<table>
<thead>
<tr>
<th>Categories</th>
<th>Targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron</td>
<td>$e^-, e^+$</td>
</tr>
<tr>
<td>Intermediate Electron</td>
<td>$\mu^-, \mu^+$</td>
</tr>
<tr>
<td>Muon</td>
<td>$\ell^+$</td>
</tr>
<tr>
<td>Intermediate Muon</td>
<td>$K^-$</td>
</tr>
<tr>
<td>KinLepton</td>
<td>$K^-, \pi^+$</td>
</tr>
<tr>
<td>Intermediate KinLepton</td>
<td>$\pi^+$</td>
</tr>
<tr>
<td>Kaon</td>
<td>$\pi^-$</td>
</tr>
<tr>
<td>KaonPion</td>
<td>$\ell^-, \pi^-$</td>
</tr>
<tr>
<td>SlowPion</td>
<td>$\ell^-, \pi^+$</td>
</tr>
<tr>
<td>FastPion</td>
<td>$\Lambda$</td>
</tr>
<tr>
<td>MaximumP</td>
<td></td>
</tr>
<tr>
<td>FSC</td>
<td></td>
</tr>
<tr>
<td>Lambda</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>13</strong></td>
</tr>
</tbody>
</table>
### Sin(2\(\beta\)) : expected errors

<table>
<thead>
<tr>
<th>(B^0 \to J/\psi K_s)</th>
<th>Belle</th>
<th>Belle II</th>
<th>leptonic categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>(S) ((50 \text{ ab}^{-1}))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>stat.</td>
<td>0.0035</td>
<td>0.0035</td>
<td>0.0060</td>
</tr>
<tr>
<td>syst. reducible</td>
<td>0.0012</td>
<td>0.0012</td>
<td>0.0012</td>
</tr>
<tr>
<td>syst. irreducible</td>
<td>0.0082</td>
<td>0.0044</td>
<td>0.0040</td>
</tr>
<tr>
<td>(A) ((50 \text{ ab}^{-1}))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>stat.</td>
<td>0.0025</td>
<td>0.0025</td>
<td>0.0043</td>
</tr>
<tr>
<td>syst. reducible</td>
<td>0.0007</td>
<td>0.0007</td>
<td>0.0007</td>
</tr>
<tr>
<td>syst. irreducible</td>
<td>+0.043</td>
<td>+0.042</td>
<td>0.011</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(b \to c \bar{c} s)</th>
<th>Belle</th>
<th>Belle II</th>
<th>leptonic categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>(S) ((50 \text{ ab}^{-1}))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>stat.</td>
<td>0.0027</td>
<td>0.0027</td>
<td>0.0048</td>
</tr>
<tr>
<td>syst. reducible</td>
<td>0.0026</td>
<td>0.0026</td>
<td>0.0026</td>
</tr>
<tr>
<td>syst. irreducible</td>
<td>0.0070</td>
<td>0.0036</td>
<td>0.0035</td>
</tr>
<tr>
<td>(A) ((50 \text{ ab}^{-1}))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>stat.</td>
<td>0.0019</td>
<td>0.0019</td>
<td>0.0033</td>
</tr>
<tr>
<td>syst. reducible</td>
<td>0.0014</td>
<td>0.0014</td>
<td>0.0014</td>
</tr>
<tr>
<td>syst. irreducible</td>
<td>0.0106</td>
<td>0.0087</td>
<td>0.0035</td>
</tr>
</tbody>
</table>

- Sin(2\(\beta\)) will remain the most precise measurement on the Unitarity Triangle parameters
- In Belle II the measurement will be dominated by systematics
  - Effort concentrated in understanding and reducing them

Three hypotheses
- Belle: same Belle non reducible systematics
- Belle II: vertex systematic / 2
- Leptonic category: only leptonic categories for the flavor tagging
Sin(2\(\beta\)): b \rightarrow q\bar{q}s

In principle measures sin2\(\beta\), but sensitive to new physics
B^0 \to \phi K_s: expected sensitivity

<table>
<thead>
<tr>
<th>Channel</th>
<th>$\varepsilon_{reco}$</th>
<th>Yield</th>
<th>$\sigma(S)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ab^{-1} scenario:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\phi(K^+K^-)K_S(\pi^+\pi^-)$</td>
<td>35%</td>
<td>456</td>
<td>0.174</td>
</tr>
<tr>
<td>$\phi(K^+K^-)K_S(\pi^0\pi^0)$</td>
<td>25%</td>
<td>153</td>
<td>0.295</td>
</tr>
<tr>
<td>$\phi(\pi^+\pi^-\pi^0)K_S(\pi^+\pi^-)$</td>
<td>28%</td>
<td>109</td>
<td>0.338</td>
</tr>
<tr>
<td>$K_S$ modes combination</td>
<td></td>
<td></td>
<td>0.135</td>
</tr>
<tr>
<td>$K_S + K_L$ modes combination</td>
<td></td>
<td></td>
<td>0.108</td>
</tr>
<tr>
<td>5 ab^{-1} scenario:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\phi(K^+K^-)K_S(\pi^+\pi^-)$</td>
<td>35%</td>
<td>2280</td>
<td>0.078</td>
</tr>
<tr>
<td>$\phi(K^+K^-)K_S(\pi^0\pi^0)$</td>
<td>25%</td>
<td>765</td>
<td>0.132</td>
</tr>
<tr>
<td>$\phi(\pi^+\pi^-\pi^0)K_S(\pi^+\pi^-)$</td>
<td>28%</td>
<td>545</td>
<td>0.151</td>
</tr>
<tr>
<td>$K_S$ modes combination</td>
<td></td>
<td></td>
<td>0.060</td>
</tr>
<tr>
<td>$K_S + K_L$ modes combination</td>
<td></td>
<td></td>
<td>0.048</td>
</tr>
</tbody>
</table>

we estimate the expected yield of $\phi K_L^0$ based on previous BaBar and Belle analyses (but use the same $\Delta t$ resolution we estimate in $\phi \to K^+K^-$ for Belle II).
B^0 \rightarrow \eta' K_S: expected sensitivity

Table 1.12: $\Delta t$ resolution for true, SxF and all selected candidates, for $\eta(2\gamma)K_S^0(\pi^\pm)$ and $\eta(3\pi)K_S^0(\pi^\pm)$ channels.

<table>
<thead>
<tr>
<th>Channel</th>
<th>True</th>
<th>SxF</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta(2\gamma)K_S^0(\pi^\pm)$</td>
<td>1.22 ps</td>
<td>2.87 ps</td>
<td>1.45 ps</td>
</tr>
<tr>
<td>$\eta(3\pi)K_S^0(\pi^\pm)$</td>
<td>1.17 ps</td>
<td>2.36 ps</td>
<td>1.50 ps</td>
</tr>
</tbody>
</table>

Similar Belle sensitivity given the same integrated luminosity

Table 1.13: Estimated rms from Toy MC studies for CP-violation parameters S and C for an integrated luminosity of 1 and 5 ab$^{-1}$ for the different channels.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Strategy</th>
<th>1 ab$^{-1}$</th>
<th>5 ab$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>S</td>
<td>rms S</td>
</tr>
<tr>
<td>$\eta(2\gamma)K_S^0(\pi^\pm)$</td>
<td>C</td>
<td>0.71</td>
<td>0.07</td>
</tr>
<tr>
<td>$\eta(3\pi)K_S^0(\pi^\pm)$</td>
<td>B</td>
<td>0.74</td>
<td>0.17</td>
</tr>
</tbody>
</table>
Measurement of $\alpha$

Proceeds mainly through $b \rightarrow u \bar{u} d d$ tree diagram, but penguin contributions introduce additional phases

\[
\sin(2\alpha) \rightarrow \sin(2\alpha_{\text{eff}}) \quad \alpha_{\text{eff}} = \alpha + \Delta\alpha
\]

To relate $\alpha$ to $\alpha_{\text{eff}}$:

\[
\frac{1}{\sqrt{2}} A^{+-} + A^{00} = A^{+0} \\
\frac{1}{\sqrt{2}} \bar{A}^{+-} + \bar{A}^{00} = \bar{A}^{-0} \\
A^{+0} = \bar{A}^{-0} \text{ (pure tree)}
\]

Used decay modes:
- $B \rightarrow \pi \pi$
- $B \rightarrow \rho \rho$
- $B \rightarrow \rho \pi$

Extra weak and strong phases + |P/T| modify $\alpha$ by $\Delta\alpha$:

Isospin analysis

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Photon conversion inside the Belle II detector (Beam pipe + PXD)

- 3% of $B^0 \rightarrow \pi^0 \pi^0$ events
- $\sim$ 5% including $\pi^0$ Dalitz decay
- Reconstruction efficiency will be crucial
Isospin analysis: $B \rightarrow \pi \pi$

<table>
<thead>
<tr>
<th>Value</th>
<th>$0.8 \text{ ab}^{-1}$</th>
<th>$50 \text{ ab}^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mathcal{B}_{\pi^+\pi^-} [10^{-6}]$</td>
<td>$5.04 \pm 0.21 \pm 0.18$ [79]</td>
<td>$\pm 0.03 \pm 0.08$</td>
</tr>
<tr>
<td>$\mathcal{B}_{\pi^0\pi^0} [10^{-6}]$</td>
<td>$1.31 \pm 0.19 \pm 0.18$ [78]</td>
<td>$\pm 0.04 \pm 0.04$</td>
</tr>
<tr>
<td>$\mathcal{B}_{\pi^+\pi^0} [10^{-6}]$</td>
<td>$5.86 \pm 0.26 \pm 0.38$ [79]</td>
<td>$\pm 0.03 \pm 0.09$</td>
</tr>
<tr>
<td>$C_{\pi^+\pi^-}$</td>
<td>$-0.33 \pm 0.06 \pm 0.03$ [80]</td>
<td>$\pm 0.01 \pm 0.03$</td>
</tr>
<tr>
<td>$S_{\pi^+\pi^-}$</td>
<td>$-0.64 \pm 0.08 \pm 0.03$ [80]</td>
<td>$\pm 0.01 \pm 0.01$</td>
</tr>
<tr>
<td>$C_{\pi^0\pi^0}$</td>
<td>$-0.14 \pm 0.36 \pm 0.12$ [78]</td>
<td>$\pm 0.03 \pm 0.01$</td>
</tr>
</tbody>
</table>

$\Delta S_{\pi^0\pi^0} = \pm 0.29 \pm 0.03$

78: arXiv:1705.02083
Isospin analysis: $B \to \rho \rho$

<table>
<thead>
<tr>
<th>Value</th>
<th>0.8 ab$^{-1}$</th>
<th>50 ab$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_{L,\rho^+\rho^-}$</td>
<td>0.988 ± 0.012 ± 0.023 [74]</td>
<td>± 0.002 ± 0.003</td>
</tr>
<tr>
<td>$f_{L,\rho^0\rho^0}$</td>
<td>0.21 ± 0.20 ± 0.15 [81]</td>
<td>± 0.03 ± 0.02</td>
</tr>
<tr>
<td>$B_{\rho^+\rho^-}$ [10$^{-6}$]</td>
<td>28.3 ± 1.5 ± 1.5 [74]</td>
<td>± 0.19 ± 0.4</td>
</tr>
<tr>
<td>$B_{\rho^0\rho^0}$ [10$^{-6}$]</td>
<td>1.02 ± 0.30 ± 0.15 [81]</td>
<td>± 0.04 ± 0.02</td>
</tr>
<tr>
<td>$C_{\rho^+\rho^-}$</td>
<td>0.00 ± 0.10 ± 0.06 [74]</td>
<td>± 0.01 ± 0.01</td>
</tr>
<tr>
<td>$S_{\rho^+\rho^-}$</td>
<td>−0.13 ± 0.15 ± 0.05 [74]</td>
<td>± 0.02 ± 0.01</td>
</tr>
<tr>
<td>Value</td>
<td>0.08 ab$^{-1}$</td>
<td>50 ab$^{-1}$</td>
</tr>
<tr>
<td>$f_{L,\rho^+\rho^0}$</td>
<td>0.95 ± 0.11 ± 0.02 [65]</td>
<td>± 0.004 ± 0.003</td>
</tr>
<tr>
<td>$B_{\rho^+\rho^0}$ [10$^{-6}$]</td>
<td>31.7 ± 7.1 ± 5.3 [65]</td>
<td>± 0.3 ± 0.5</td>
</tr>
<tr>
<td>Value</td>
<td>0.5 ab$^{-1}$</td>
<td>50 ab$^{-1}$</td>
</tr>
<tr>
<td>$C_{\rho^0\rho^0}$</td>
<td>0.2 ± 0.8 ± 0.3 [64]</td>
<td>± 0.08 ± 0.01</td>
</tr>
<tr>
<td>$S_{\rho^0\rho^0}$</td>
<td>0.3 ± 0.7 ± 0.2 [64]</td>
<td>± 0.07 ± 0.01</td>
</tr>
</tbody>
</table>


Belle Belle II Belle II + (S$_{00}\pi$ & S$_{00}\rho$)
Measurement of $\gamma$ with $B \to D^0 K$

$\gamma$ is the phase between $b \to u$ and $b \to c$:

$$e^{i\delta_B} e^{-i\gamma}$$

Interference between these amplitudes with $D^0/\bar{D}^0$ decaying in the same final state:

- From tree level processes
- Not affected from NP in loops

$$D^0/\bar{D}^0 \to Ks \, \pi^+ \, \pi^-$$

Strong phase differences can be measured at a charm factory:

- CLEO result \cite{PhysRevD.82.112006}
- Improvement expected from BES III

An error of $1.6^\circ$ is expected

- Including more $D^{(*)}$ decay modes
- Integrated luminosity = 50 ab$^{-1}$
- Assuming BES III will collect 10 fb$^{-1}$

The Dalitz model is needed

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Outlook

The B2TIP report: https://confluence.desy.de/display/BI/B2TIP+WebHome

CKM mechanism will be tested at 1% level

Before the B-factories

After the B-factories

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Backup slides
Belle II

**Time of Propagation counter**
with 20 mm quartz bars
MCP-PMT readout

**K^0_L/µ Detector (outside)**
RPC Plates and plastic scintillators with SIPM readout

**Superconducting Magnet**
homogeneous field of 1.5 T

**Electromagnetic Calorimeter**
8000 CsI Crystals, 16 X_0
PMT/APD readout

**Pixel Vertex Detector**
2 layer pixel detector (8MP)
DEPFET technology

**Silicon Vertex Detector**
4 layer double sided strips
20 – 50 ns shaping time

**Central Drift Chamber**
proportional wire drift chamber
15000 sense wires in 58 layers

**Aerogel RICH**
Proximity focusing RICH with silica aerogel
The impact parameter

The impact parameters: $d_0$ and $z_0$
- defined as the projections of distance from the point of closest approach to the origin
- good measure of the overall performance of the tracking system
- used to find the optimal tracker configuration

Almost a factor 2 improvement respect to BaBar
Belle Data – MC comparison

Efficiency
- Belle Converted MC = 32 %
- Belle = 29 %
$B^0 \rightarrow \phi Ks$

1) $\phi \rightarrow K_S^0 \rightarrow \pi^+\pi^-$
   Cleanest mode, all charged particles in final state
   $K^+K^-$

2) $\phi \rightarrow K_S^0 \rightarrow \pi^0\pi^0$
   Lower statistics and harder (because of $\pi^0$'s)
   $K^+K^-$

3) $\phi \rightarrow K_S^0 \rightarrow \pi^+\pi^-$
   Never tried before at BaBar and Belle
   $\pi^+\pi^-\pi^0$

4) $\phi \rightarrow K_L^0$
   Not yet started looking at $K_L^0$'s
   $K^+K^-$

BF($\phi \rightarrow K^+K^-$) $\sim$ 50%
BF($\phi \rightarrow \pi^+\pi^-\pi^0$) $\sim$ 15%
BF($K_S \rightarrow \pi^+\pi^-$) $\sim$ 69%
BF($K_S \rightarrow \pi^0\pi^0$) $\sim$ 31%
Vertex resolution

Using “iptube” + $K_S^0$ flight direction constraints

$\phi \rightarrow K^+K^-$
resolution: 0.752 ps

$\phi \rightarrow \pi^+\pi^0\pi^0$
resolution: 0.777 ps

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Δt resolution

\[ B^{0}_{sc} \rightarrow \pi^{0}_{ss} \pi^{0}_{sc} \]
\[ \rightarrow \gamma_s \gamma_c \]
\[ \rightarrow e^+ e^- \]

\[ B^{0}_{dal} \rightarrow \pi^{0}_{ss} \pi^{0}_{dal} \]
\[ \rightarrow e^+ e^- \gamma \]

At least one track (\(e^+\) or \(e^-\)) has one PXD Hit

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$B^0 \rightarrow \rho^+ \rho^-$

Flavor integrated

$\mathcal{B}(B^0 \rightarrow \rho^+ \rho^-) = (28.3 \pm 1.5 \text{ (stat)} \pm 1.5 \text{ (syst)}) \times 10^{-6}$,

$f_L = 0.988 \pm 0.012 \text{ (stat)} \pm 0.023 \text{ (syst)}$,

$A_{CP} = 0.00 \pm 0.10 \text{ (stat)} \pm 0.06 \text{ (syst)}$,

$S_{CP} = -0.13 \pm 0.15 \text{ (stat)} \pm 0.05 \text{ (syst)}$.

- Precision improvement with respect to the previously published result is factor 2.
- Increase of data, simultaneous extraction of observables and analysis optimization for high signal yield.
BaBar + Belle $B^0 \rightarrow D_{CP} h^0$

- Leading order: tree
- Sub-leading order: tree, phase within the SM
- Independent form NP in loops
- Suitable to measure $\beta$
- Branching fraction is the limiting factor

$B^0 \rightarrow D(\ast)^0 h^0, h^0 = \pi^0, \eta, \omega$

$D^0 \rightarrow K^+ K^-, K_s \pi^0$ and $K_s \omega$

Yields =
- $508\pm31$ events (BaBar)
- $757\pm44$ events (Belle)

$-\eta_f S = +0.66 \pm 0.10 \text{ (stat.) } \pm 0.06 \text{ (syst.)}$,

$C = -0.02 \pm 0.07 \text{ (stat.) } \pm 0.03 \text{ (syst.)}$.

- First observation of CPV(5.4$\sigma$)
- Belle II : $\delta(\beta) \sim 0.015$
- Important test for $b \rightarrow c \bar{c} s$

Phys. Rev. Lett. 115, 121604

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\[ \cos 2\beta \text{ with } B^0 \to D_{CP} h^0 \]

D\(^0\) multi-body decay: D\(^0\) → Ks \(\pi\) \(\pi\) model independent

\(\cos 2\beta\) and \(\sin 2\beta\) can be extracted independently PLB 6241 (2005)

\[ C_i = \frac{\int |A_D| |\bar{A}_D| \cos \Delta \delta_D \, dm^2_+ \, dm^2_-}{\sqrt{K_i K_{-i}}} \]

\[ S_i = \frac{\int |A_D| |\bar{A}_D| \sin \Delta \delta_D \, dm^2_+ \, dm^2_-}{\sqrt{K_i K_{-i}}} \]

\[ \mathcal{P}_i(\Delta t, \varphi_1) = h_2 e^{-\frac{|\Delta t|}{\tau_B}} \left[ 1 + q_B \frac{K_i - K_{-i}}{K_i + K_{-i}} \cos(\Delta m_B \Delta t) + 2q_B \xi h^0 (-1)^L \frac{\sqrt{K_i K_{-i}}}{K_i + K_{-i}} \sin(\Delta m_B \Delta t) (S_i \cos 2\varphi_1 + C_i \sin 2\varphi_1) \right] \]

\[ \sin 2\varphi_1 = 0.43 \pm 0.27 \text{(stat)} \pm 0.08 \text{(syst)} , \]

\[ \cos 2\varphi_1 = 1.06 \pm 0.33 \text{(stat)}^{+0.21}_{-0.15} \text{(syst)} , \]

\[ \varphi_1 = 11.7^\circ \pm 7.8^\circ \text{(stat)} \pm 2.1^\circ \text{(syst)} . \]
Photon polarization

Radiative B decays, with $b \rightarrow s \gamma$ transitions, dominated by loop (penguin) diagrams

New physics could enter at same order (1-loop) as Standard Model

Standard Model makes definite prediction of photon helicity


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

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

- Rate $\sim m_s/m_b$ at the leading contribution (P. Ball and R. Zwicky, Phys. Lea. B 642, 478 (2006))
- Corrections can increase this value

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)

$$S^{SM} = - \sin 2\phi_1 \frac{m_s}{m_b} \left[ 2 + \mathcal{O}(\alpha_s) \right] + S^{SM, s\gamma g}$$

$C < 0.01$ (direct CP violation) (Greub at al., Nucl. Phys B 434, 39 (1995))

- TD CP asymmetry measurements give an indirect measurement of photon polarization
$B^0 \rightarrow K_s \pi^0 \gamma$ : TD analysis

No significant CP asymmetry

$S_{K_s^0\pi^0\gamma} = -0.10 \pm 0.31 \text{(stat)} \pm 0.07 \text{(syst)}$,

$A_{K_s^0\pi^0\gamma} = -0.20 \pm 0.20 \text{(stat)} \pm 0.06 \text{(syst)}$,

No significant CP asymmetry

$S_{K^{*0}\gamma} = -0.32^{+0.36}_{-0.33} \pm 0.05$

$A_{K^{*0}\gamma} = -0.20 \pm 0.24 \pm 0.05$
Very important decay mode for Belle II