CP Violation prospects at the Belle II Experiment

Luigi Li Gioi – for the Belle II collaboration
Max-Planck-Institut für Physik, München

LIO International Conference on Flavour Physics
“From Flavour to New Physics”
April 19th 2018
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!

Two notations for the CKM angles: $\alpha, \beta, \gamma$ or $\phi_1, \phi_2, \phi_3$
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

\[ P(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} \left[ 1 + q \left( A_{CP} \cos \Delta m_d \Delta t + S_{CP} \sin \Delta m_d \Delta t \right) \right] \]
\[ \sin(2\beta) : b \rightarrow c\bar{c}s \]


Irreducible systematic errors:
- Vertexing (without detector upgrade)
- Tag-side interference
  - More sophisticated treatment will be considered

Irreducible systematic errors:
- Vertexing (without detector upgrade)
- Tag-side interference
  - More sophisticated treatment will be considered

**TABLE II.** CP violation parameters for each \( B^0 \rightarrow f_{CP} \) mode and from the simultaneous fit for all modes together. The first and second errors are statistical and systematic uncertainties, respectively.

<table>
<thead>
<tr>
<th>Decay mode</th>
<th>( \sin 2\phi_1 = -\xi_f S_f )</th>
<th>( A_f )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( J/\psi K_S^0 )</td>
<td>+0.670 ± 0.029 ± 0.013</td>
<td>-0.015 ± 0.021+0.045-0.023</td>
</tr>
<tr>
<td>( \psi(2S)K_S^0 )</td>
<td>+0.738 ± 0.079 ± 0.036</td>
<td>+0.104 ± 0.055+0.047-0.027</td>
</tr>
<tr>
<td>( \chi c\bar{c} K_S^0 )</td>
<td>+0.640 ± 0.117 ± 0.040</td>
<td>-0.017 ± 0.083+0.046-0.026</td>
</tr>
<tr>
<td>( J/\psi K_L^0 )</td>
<td>+0.642 ± 0.047 ± 0.021</td>
<td>+0.019 ± 0.026+0.017-0.041</td>
</tr>
<tr>
<td>All modes</td>
<td>+0.667 ± 0.023 ± 0.012</td>
<td>+0.006 ± 0.016 ± 0.012</td>
</tr>
</tbody>
</table>

**TABLE II.** CP violation parameters for each \( B^0 \rightarrow f_{CP} \) mode and from the simultaneous fit for all modes together. The first and second errors are statistical and systematic uncertainties, respectively.

<table>
<thead>
<tr>
<th>Source</th>
<th>Irreducible Error on ( S )</th>
<th>Error on ( A )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertexing</td>
<td>X</td>
<td>±0.007</td>
</tr>
<tr>
<td>( \Delta t ) resolution</td>
<td></td>
<td>±0.007</td>
</tr>
<tr>
<td>Tag-side interference</td>
<td>X</td>
<td>±0.001</td>
</tr>
<tr>
<td>Flavor tagging</td>
<td></td>
<td>±0.004</td>
</tr>
<tr>
<td>Possible fit bias</td>
<td></td>
<td>±0.004</td>
</tr>
<tr>
<td>Signal fraction</td>
<td></td>
<td>±0.004</td>
</tr>
<tr>
<td>Background ( \Delta t ) PDFs</td>
<td></td>
<td>±0.001</td>
</tr>
<tr>
<td>Physics parameters</td>
<td></td>
<td>±0.001</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>±0.012</td>
</tr>
</tbody>
</table>

FIG. 2 (color online). The background-subtracted \( \Delta t \) distribution (top) for \( q = +1 \) (red) and \( q = -1 \) (blue) events and asymmetry (bottom) for good tag quality (\( r > 0.5 \)) events for all CP-odd modes combined (left) and the CP-even mode (right).
SuperKEKB

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

LIO 2018 Luigi Li Gioi
Belle II

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

**$K^0_L / \mu$ 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
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
The impact parameters: $d_0$ and $z_0$

- defined as the projections of distance from the point of closest approach to the origin

A factor 2 improvement with respect to Belle
**Vertex fit**

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

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

- **Belle II**:
  - Resolution = 26 $\mu$m

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

### $\Delta t$ resolution

- **Belle II**:
  - Bias = -0.03 ps
  - Resolution = 0.77 ps

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

### Tag side vertex fit

- **Belle II**:
  - Bias = 6 $\mu$m
  - Resolution = 53 $\mu$m

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

Categories | Targets for $\bar{B}^0$
--- | ---
Electron | $e^-, e^+$
Intermediate Electron | $\mu^-, \mu^+$
Muon | $\pi^+$
Intermediate Muon | $l^-$
Kinetic Lepton | $l^+$
Intermediate Kinetic Lepton | $K^-$
Kaon | $K^-, \pi^+$
Kaon-Pion | $\pi^+$
Slow Pion | $\pi^-$
Maximum P* | $l^-, \pi^-$
Fast-Slow-Correlated (FSC) | $l^-, \pi^+$
Fast Hadron | $\pi^-, K^-$
Lambda | $\Lambda$

Underlying decay modes

$\bar{B}^0 \rightarrow D^{*+} \bar{\nu}_\ell \ell^-$
$\rightarrow D^0 \pi^+$
$\rightarrow X K^-$

$\bar{B}^0 \rightarrow D^+ \pi^- (K^-)$
$\rightarrow K^0 \nu_\ell \ell^+$

$\bar{B}^0 \rightarrow A_c^+ X^-$
$\rightarrow \Lambda \pi^+$
$\rightarrow p \pi^-$

Belle II MC = $37.16 \pm 0.03\%$
Belle Data – MC comparison

- Belle MC and data
- Belle II flavor tagging algorithm

More than 10% efficiency increase on the same dataset

Efficiency
- Belle Data (assuming linearity) = 33.6 ± 0.5 %
- Belle Converted MC = 34.18 ± 0.03 %
- Belle old FT Data = 30.1 ± 0.4 %
- Belle II MC = 37.16 ± 0.03 %

### FBDT Combiner

<table>
<thead>
<tr>
<th>$r$-Interval</th>
<th>$\varepsilon_i$</th>
<th>$w_i \pm \delta w_i$</th>
<th>$\varepsilon_{\text{eff},i} \pm \delta \varepsilon_{\text{eff},i}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000 – 0.100</td>
<td>15.49</td>
<td>47.61 ± 0.04</td>
<td>0.035 ± 0.002</td>
</tr>
<tr>
<td>0.100 – 0.250</td>
<td>15.81</td>
<td>41.42 ± 0.06</td>
<td>0.465 ± 0.014</td>
</tr>
<tr>
<td>0.250 – 0.500</td>
<td>19.88</td>
<td>31.57 ± 0.09</td>
<td>2.695 ± 0.066</td>
</tr>
<tr>
<td>0.500 – 0.625</td>
<td>10.68</td>
<td>21.87 ± 0.06</td>
<td>3.375 ± 0.110</td>
</tr>
<tr>
<td>0.625 – 0.750</td>
<td>11.52</td>
<td>15.68 ± 0.06</td>
<td>5.416 ± 0.169</td>
</tr>
<tr>
<td>0.750 – 0.875</td>
<td>9.68</td>
<td>9.39 ± 0.07</td>
<td>6.372 ± 0.219</td>
</tr>
<tr>
<td>0.875 – 1.000</td>
<td>16.77</td>
<td>2.32 ± 0.05</td>
<td>15.226 ± 0.382</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$\varepsilon_{\text{eff}} = \sum \varepsilon_i \cdot (1 - 2w_i)^2$</td>
<td>33.6 ± 0.5</td>
<td></td>
</tr>
</tbody>
</table>
Sin(2β) : expected errors

<table>
<thead>
<tr>
<th>Channel</th>
<th>WA (2017)</th>
<th>5 ab⁻¹</th>
<th>50 ab⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>σ(S)</td>
<td>σ(A)</td>
<td>σ(S)</td>
</tr>
<tr>
<td>J/ψK⁰</td>
<td>0.022</td>
<td>0.021</td>
<td>0.012</td>
</tr>
<tr>
<td>φK⁰</td>
<td>0.12</td>
<td>0.14</td>
<td>0.048</td>
</tr>
<tr>
<td>η'K⁰</td>
<td>0.06</td>
<td>0.04</td>
<td>0.032</td>
</tr>
<tr>
<td>ωK⁰</td>
<td>0.21</td>
<td>0.14</td>
<td>0.08</td>
</tr>
</tbody>
</table>

- Sin(2β) will remain the most precise measurement on the Unitarity Triangle parameters
- In Belle II the measurement will be dominated by systematics
  - Effort concentrated in understand and reducing them
  - A precision of 1% is expected using the b → ccs decay modes
In principle measures $\sin 2\beta$, but sensitive to new physics

$$\sin(2\beta^{\text{eff}}) = \sin(2\phi_1^{\text{eff}})$$
\[ \mathbf{B}^\circ \rightarrow \phi \text{ Ks: expected sensitivity} \]

<table>
<thead>
<tr>
<th>Channel</th>
<th>( \varepsilon_{\text{reco}} )</th>
<th>Yield</th>
<th>( \sigma(S) )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1 ab(^{-1}) scenario:</strong></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 \text{ modes combination} )</td>
<td></td>
<td></td>
<td>0.135</td>
</tr>
<tr>
<td>( K_S + K_L \text{ modes combination} )</td>
<td></td>
<td></td>
<td>0.108</td>
</tr>
<tr>
<td><strong>5 ab(^{-1}) scenario:</strong></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 \text{ modes combination} )</td>
<td></td>
<td></td>
<td>0.060</td>
</tr>
<tr>
<td>( K_S + K_L \text{ 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 \( \phi \rightarrow K^+K^- \) for Belle II).
$\mathbf{B^0 \rightarrow \eta' \ K_s: \text{expected sensitivity}}$

Similar Belle sensitivity given the same integrated luminosity

<table>
<thead>
<tr>
<th>Channel</th>
<th>yield</th>
<th>$\sigma(S_f)$</th>
<th>$\sigma(A_f)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta'(\eta_{\gamma\gamma} \pi^\pm) K_S^{(\pm)}$</td>
<td>969</td>
<td>0.13</td>
<td>0.08</td>
</tr>
<tr>
<td>$\eta'(\eta_{\gamma\gamma} \pi^\pm) K_S^{(00)}$</td>
<td>215</td>
<td>0.27</td>
<td>0.17</td>
</tr>
<tr>
<td>$\eta'(\eta_3 \pi^\pm) K_S^{(\pm)}$</td>
<td>283</td>
<td>0.25</td>
<td>0.16</td>
</tr>
<tr>
<td>$\eta'(\rho_{\gamma}) K_S^{(\pm)}$</td>
<td>2100</td>
<td>0.09</td>
<td>0.05</td>
</tr>
<tr>
<td>$\eta'(\rho_{\gamma}) K_S^{(00)}$</td>
<td>320</td>
<td>0.22</td>
<td>0.14</td>
</tr>
<tr>
<td>$K_S^0$ modes</td>
<td>3891</td>
<td>0.065</td>
<td>0.040</td>
</tr>
<tr>
<td>$K_L^0$ modes</td>
<td>1546</td>
<td>0.17</td>
<td>0.11</td>
</tr>
<tr>
<td>$K_S^0 + K_L^0$ modes</td>
<td>5437</td>
<td>0.060</td>
<td>0.038</td>
</tr>
<tr>
<td>$\int L = 50 \text{ ab}^{-1}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\eta'(\eta_{\gamma\gamma} \pi^\pm) K_S^{(\pm)}$</td>
<td>4840</td>
<td>0.06</td>
<td>0.04</td>
</tr>
<tr>
<td>$\eta'(\eta_{\gamma\gamma} \pi^\pm) K_S^{(00)}$</td>
<td>1070</td>
<td>0.12</td>
<td>0.09</td>
</tr>
<tr>
<td>$\eta'(\eta_3 \pi^\pm) K_S^{(\pm)}$</td>
<td>1415</td>
<td>0.11</td>
<td>0.08</td>
</tr>
<tr>
<td>$\eta'(\rho_{\gamma}) K_S^{(\pm)}$</td>
<td>10500</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>$\eta'(\rho_{\gamma}) K_S^{(00)}$</td>
<td>1600</td>
<td>0.10</td>
<td>0.07</td>
</tr>
<tr>
<td>$K_S^0$ modes</td>
<td>19500</td>
<td>0.028</td>
<td>0.021</td>
</tr>
<tr>
<td>$K_L^0$ modes</td>
<td>7730</td>
<td>0.08</td>
<td>0.05</td>
</tr>
<tr>
<td>$K_S^0 + K_L^0$ modes</td>
<td>27200</td>
<td>0.027</td>
<td>0.020</td>
</tr>
</tbody>
</table>
BaBar + Belle $B^0 \to D_{CP} h^0$

- 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

$B^0 \to D^{(*)0} h^0$, $h^0 = \pi^0$, $\eta$, $\omega$
$D^0 \to K^+ K^-$, $K_s \pi^0$ and $K_s \omega$
Yields =
- $508 \pm 31$ events (BaBar)
- $757 \pm 44$ events (Belle)

$-\eta_f S = +0.66 \pm 0.10$ (stat.) $\pm 0.06$ (syst.),
$C = -0.02 \pm 0.07$ (stat.) $\pm 0.03$ (syst.).

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

M. Gronau and D. London, PRL 65 3381 (1990)

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

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

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

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

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

Isospin analysis:

$$\frac{1}{\sqrt{2}} A_{+} = A_{00}$$
$$\frac{1}{\sqrt{2}} \bar{A}_{-} = \bar{A}_{00}$$
$$2\Delta \phi_{2}$$

$A_{+0} = \bar{A}_{-0}$

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

Luigi Li Gioi
B^0 \rightarrow \pi^0\pi^0 : converted photons

- 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: $B \rightarrow \pi \pi$

$$\Delta \alpha \sim 4^\circ$$

<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 ± 0.21 ± 0.18 [79]</td>
<td>±0.03 ± 0.08</td>
</tr>
<tr>
<td>$\mathcal{B}_{\pi^0\pi^0}$ [$10^{-6}$]</td>
<td>1.31 ± 0.19 ± 0.18 [78]</td>
<td>±0.04 ± 0.04</td>
</tr>
<tr>
<td>$\mathcal{B}_{\pi^+\pi^0}$ [$10^{-6}$]</td>
<td>5.86 ± 0.26 ± 0.38 [79]</td>
<td>±0.03 ± 0.09</td>
</tr>
<tr>
<td>$C_{\pi^+\pi^-}$</td>
<td>−0.33 ± 0.06 ± 0.03 [80]</td>
<td>±0.01 ± 0.03</td>
</tr>
<tr>
<td>$S_{\pi^+\pi^-}$</td>
<td>−0.64 ± 0.08 ± 0.03 [80]</td>
<td>±0.01 ± 0.01</td>
</tr>
<tr>
<td>$C_{\pi^0\pi^0}$</td>
<td>−0.14 ± 0.36 ± 0.12 [78]</td>
<td>±0.03 ± 0.01</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Value</th>
<th>$0.8 \text{ ab}^{-1}$</th>
<th>$50 \text{ ab}^{-1}$</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>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Value</th>
<th>$0.08 \text{ ab}^{-1}$</th>
<th>$50 \text{ ab}^{-1}$</th>
</tr>
</thead>
<tbody>
<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>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Value</th>
<th>$0.5 \text{ ab}^{-1}$</th>
<th>$50 \text{ ab}^{-1}$</th>
</tr>
</thead>
<tbody>
<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})

Δα ~ 0.7°
Δα ~ 0.6°
Measurement of $\gamma$ with $B \to D^0 K$

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

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

Interference between these amplitudes with $D^0/D^0$ decaying in the same final state

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

Strong phase differences can be measured at a charm factory

- Improvement expected from BES III

An error of 1.6° is expected
- Including more $D^{(*)}$ decay modes
- Integrated luminosity = 50 ab$^{-1}$
- Assuming BES III will collect 10 fb$^{-1}$
Photon polarization

Radiative B decays, with $b \to s \gamma$ 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
- $B^0 \to X_s \gamma_R$
- $\bar{B}^0 \to X_s \gamma_L$

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

$$S_{K^0\pi^0\gamma}^{SM} \sim -2 \frac{m_s}{m_b} \sin 2\phi_1 = -(2.3 \pm 1.6)\%$$


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

- TD CP asymmetry measurements give an indirect measurement of photon polarization
$B^0 \to Ks \pi^0 \gamma$

Very important decay mode for Belle II
$B^0 \rightarrow K_S \pi^+ \pi^- \gamma$

Signal definition

$B^0 \rightarrow \gamma \cdot K^0_1(1270)$

$\gamma \cdot K^{*\pm}(892)\pi^\mp$

$\gamma \cdot K_S^0 \rho(770)$

$K_S^0 \pi^\pm \pi^\mp \gamma$

Generated Dalitz plot

- TDCVP analysis
- Fit the Dalitz plot
- Maximize the sensitivity

Complete sensitivity study

Belle II MC

Belle II MC

Belle II MC

Belle II MC

Belle II MC

Belle II MC

BaBar: PRD 93 (2016) 052013
Outlook

The Belle II Physics Book: https://confluence.desy.de/display/BI/B2TiP+WebHome

Before the B-factories

After the B-factories

CKM mechanism will be tested at 1% level
Backup slides
$B \to \pi \pi$: Isospin Triangle

Parametrization by M. Pivk and F. R. Le Diberder  

Without $S(\pi^0\pi^0)$

With $S(\pi^0\pi^0)$
$B \to \rho \rho$ : Isospin Triangle
**Sin(2β) : expected errors**

<table>
<thead>
<tr>
<th>B⁰ → J/ψ Ks</th>
<th>Belle</th>
<th>Belle II</th>
<th>leptonic categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>S (50 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 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 → c ¯c s</th>
<th>Belle</th>
<th>Belle II</th>
<th>leptonic categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>S (50 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 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(2β) 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