Current Status
for $CP$ Violation Measurements

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*the Belle collaboration*

*the Belle II collaboration*

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Physics at LHC and Beyond
# Belle/KEKB, BaBar/PEP-II

<table>
<thead>
<tr>
<th>Accelerator</th>
<th>Detector</th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Belle</strong></td>
<td><img src="image1" alt="KEKB" /></td>
<td><img src="image2" alt="Belle" /></td>
</tr>
<tr>
<td><strong>BaBar</strong></td>
<td><img src="image3" alt="PEP-II" /></td>
<td><img src="image4" alt="BaBar" /></td>
</tr>
</tbody>
</table>

# LHC; DØ+CDF/Tevatron

<table>
<thead>
<tr>
<th>Accelerator</th>
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</thead>
<tbody>
<tr>
<td>ATLAS, CMS, LHCb</td>
<td><img src="image1.png" alt="LHC" /></td>
<td></td>
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<tr>
<td>DØ, CDF</td>
<td><img src="image2.png" alt="CDF" /></td>
<td>$\sim 11 \text{ fb}^{-1}$</td>
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</tbody>
</table>
Unitarity Triangle

- $\phi_1 = (21.50^{+0.75}_{-0.74})^0$ (CKMfitter winter-2014)
  - $S_{c\bar{c}s} (\sin2\phi_{1\text{eff}}) = 0.682 \pm 0.019$ (HFAG winter-2014)
    - Belle (772M $B\bar{B}$ at Y(4S)): 0.667 $\pm$ 0.023 $\pm$ 0.012
    - BaBar (465M $B\bar{B}$ Y(4S)): 0.687 $\pm$ 0.028 $\pm$ 0.012
    - Belle (121fb$^{-1}$ at Y(5S) $\rightarrow B^0B^+\pi^-)$: 0.57 $\pm$ 0.58 $\pm$ 0.06
      - The neutral $B$ meson flavor is tagged by the pion charge.
    - LHCb (1.0 fb$^{-1}$): 0.73 $\pm$ 0.07 $\pm$ 0.04
  - Manifestation of the time-dependent $CP$ violation
    - Belle/BaBar: proper time difference of the two $B$ mesons ($\Delta t$).
    - LHCb: absolute decay time of the $B$ meson ($t$).
Unitarity Triangle

- $\phi_2 = (85.4^{+4.0}_{-3.9})^0$ (CKMfitter winter-2014)
- $S_{\pi^+\pi^-}(\sin 2\phi_{2\text{eff}}) = -0.66 \pm 0.06$ (HFAG winter-2014)
  - Belle (772M $B\bar{B}$ at $Y(4S)$): $-0.64 \pm 0.08 \pm 0.03$
  - BaBar (467M $B\bar{B}$ $Y(4S)$): $-0.68 \pm 0.10 \pm 0.03$
  - LHCb (1.0 fb$^{-1}$): $-0.71 \pm 0.13 \pm 0.02$
- $\phi_3 = (70.0^{+7.7}_{-9.0})^0$ (CKMfitter winter-2014)

- **Tensions** (CKMfitter winter-2014)
  - $\sigma_{\sin 2\phi_1} = 1.96$
  - $\sigma_{\phi_2} = 1.56$
  - $\sigma_{\phi_3} = 0.41$

\[ \rho \]

**CP Violation in $b \rightarrow sq\bar{q}$ Transition**

- **Probe of a new physics (NP) beyond the SM**
  - Charmless $B$ decays mediated by $b \rightarrow sq\bar{q}$ transition is sensitive to the NP that appears in the loop.

  - Deviation of $\delta S \equiv S_{c\bar{c}s} - S_{sq\bar{q}}$ from the SM expectation of $O(0.01–0.1)$ will indicate the NP.
**CP Violation in \(b \rightarrow sq\bar{q} \) Transition**

- \(B^0 \rightarrow \eta'K^{*0}\)  
  \((K^{*0} \rightarrow K^+\pi^-, \eta' \rightarrow \eta\pi\pi)\)
  - Four-dim. fit of the \(B^0\) mass, energy, \(B^0 \leftrightarrow K^{*0}\) helicity angle, and \(q\bar{q}\) BG likelihood to the corresponding distributions gives \(Br = (2.6 \pm 0.7 \pm 0.2) \times 10^{-6}\).
  - The first \(5\sigma\) measurement.

- The direct \(CP\)-violating parameter is determined as well:

\[
A_{CP}(\eta'K^{*0}) = \frac{\Gamma(\overline{B}^0 \rightarrow \eta'K^-\pi^+) - \Gamma(B^0 \rightarrow \eta'K^+\pi^-)}{\Gamma(\overline{B}^0 \rightarrow \eta'K^-\pi^+) + \Gamma(B^0 \rightarrow \eta'K^+\pi^-)} = (-0.22 \pm 0.29 \pm 0.07)
\]
**CP Violation in $b\rightarrow sq\bar{q}$ Transition**

- $B^0 \rightarrow \eta'K^0$ ($\eta' \rightarrow \rho\gamma, \eta\pi\pi$)

  (HFAG winter-2014)

<table>
<thead>
<tr>
<th></th>
<th>$-\xi_f S_f$</th>
<th>$A_f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belle</td>
<td>+0.68 ± 0.07 ± 0.03</td>
<td>+0.03 ± 0.05 ± 0.04</td>
</tr>
<tr>
<td>BaBar</td>
<td>+0.57 ± 0.08 ± 0.02</td>
<td>+0.08 ± 0.06 ± 0.02</td>
</tr>
<tr>
<td>Average</td>
<td>+0.63 ± 0.06</td>
<td>+0.05 ± 0.04</td>
</tr>
</tbody>
</table>

- The $-\xi_f S_f$ is consistent with $S_{c\bar{c}S}$.

Belle preliminary ($772M B\bar{B}$); BaBar, PRD 79, 052003 (2009) ($467M B\bar{B}$).
**Kπ Puzzle in B→Kπ**

- **The Kπ puzzle in B→Kπ**

<table>
<thead>
<tr>
<th>Experiment</th>
<th>( A_{CP}(K^+\pi^-) )</th>
<th>( A_{CP}(K^+\pi^0) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belle</td>
<td>(-0.069\pm0.014\pm0.014)</td>
<td>(+0.043\pm0.024\pm0.002)</td>
</tr>
<tr>
<td>BaBar</td>
<td>(-0.107\pm0.016^{+0.006}_{-0.004})</td>
<td>(+0.030\pm0.039\pm0.010)</td>
</tr>
</tbody>
</table>

Non-zero \([A_{CP}(K^+\pi^-)-A_{CP}(K^+\pi^0)]\) indicates the effect of color-suppressed EW penguin amplitudes are significant.

- **The isospin sum rule**

\[
A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+) \frac{B(K^0\pi^+)}{B(K^+\pi^-)} \frac{\tau_0}{\tau_+} = A_{CP}(K^+\pi^0) 2B(K^0\pi^0) \frac{\tau_0}{B(K^+\pi^-)} \frac{\tau_0}{\tau_+} + A_{CP}(K^0\pi^0) 2B(K^0\pi^0) \frac{\tau_0}{B(K^+\pi^-)} \frac{\tau_0}{\tau_+}
\]

- NP contribution can be probed via the sum rule violation.
- Present deviation = 1.9σ (Belle).
**Kπ Puzzle in B→K*π**

- **Kπ puzzle in B→K*π**
  - The direct CP violation measurement in B→K*π can be another approach to the Kπ puzzle solution.

<table>
<thead>
<tr>
<th>Decay</th>
<th>Direct CP violation</th>
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<tbody>
<tr>
<td>K⁰π⁺π⁰</td>
<td>0.07 ± 0.05 ± 0.03 ± 0.04</td>
</tr>
<tr>
<td>K⁺⁺(892)π⁺</td>
<td>-0.12 ± 0.21 ± 0.08 ± 0.11</td>
</tr>
<tr>
<td>K⁺⁺(892)π⁰</td>
<td>-0.52 ± 0.14 ± 0.04 ± 0.04</td>
</tr>
<tr>
<td>K⁰⁺(1430)π⁺</td>
<td>0.14 ± 0.10 ± 0.04 ± 0.14</td>
</tr>
<tr>
<td>K⁺⁺(1430)π⁰</td>
<td>0.26 ± 0.12 ± 0.08 ± 0.12</td>
</tr>
<tr>
<td>ρ⁺⁺(770)K⁰</td>
<td>0.21 ± 0.19 ± 0.07 ± 0.30</td>
</tr>
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</table>

The first evidence (3.4σ) of the direct CP violation in B⁺→K⁺⁺π⁰ is obtained. The first measurements of $Br(B⁺→K⁰π⁺π⁰$ (inclusive)) = (45.9±2.6±3.0±8.6)x10⁻⁶ and $Br(B⁺→K⁺⁺(1430)π⁰) = (17.2±2.4±1.5±1.8)x10⁻⁶$ are obtained as well.

- Kinematical parameters ($m_{K⁰π⁺}$, $m_{K⁰π⁰}$) are used to isolate several $K⁰π⁺$ resonances in the data sample.
Dimuon Charge Asymmetry

- Dimuon charge asymmetry: \( A_{CP} \equiv \frac{N_{ev}(\mu^+ \mu^+) - N_{ev}(\mu^- \mu^-)}{N_{ev}(\mu^+ \mu^+) + N_{ev}(\mu^- \mu^-)} \)
  - \( N_{ev}(\mu^\pm \mu^\pm) \) ... number of events with same charge primary muons in the final state.

- SM prediction: \( A_{CP} = (-2.3^{+0.5}_{-0.6}) \times 10^{-4} \)

- Measurement by the DØ

\[ DØ, \text{ PRD 89, 012002 (2014) (10.4 fb}^{-1}). \]

All categories combined.

\[ A_{CP} = (-0.235^{+0.065}_{-0.055})\%, \quad 3.6\sigma \text{ deviation from the SM prediction.} \]

Hint for the NP?
**B Meson Lifetimes**

- *B* meson lifetimes = very important inputs to measure the time-dependent *CP* violation
  
  - World averages (HFAG winter-2014):
    \[
    (\tau_{B^0}, \tau_{B^+}, \tau_{B_s})
    = (1.519 \pm 0.005, 1.638 \pm 0.004, 1.512 \pm 0.007) \text{ ps}.
    \]

- **Remark: LHCb method**

  Direct measurement of the decay time distribution \(\exp(-t/\tau_B)\) enables to determine the resolution function more precisely than Belle/BaBar that measures the proper time *difference* distribution \(\exp(-|\Delta t|/\tau_B)\). The LHCb presented world best single measurement (arXiv:1402.2554).
**B_s^-\bar{B}_s Mixing**

- **B_s^-\bar{B}_s mixing** $\Delta m_s = \text{another important input}
  
  - The $\Delta m_s$ is a key input to access to the CP-violating phase $\phi_s$ of the $B_s$ system.
  
  - Since the $B_s^-\bar{B}_s$ oscillates very frequently, a large boost of the $B_s$ (equivalent to a high resolution detector) is needed to observe the oscillation structure in the $t$ distribution.

- **World average
  
  - $\Delta m_s = 17.761 \pm 0.022 \text{ ps}^{-1}$.
    
    - LHCb: $17.768 \pm 0.023 \pm 0.006 \text{ ps}^{-1}$.
    
    - CDF: $17.77 \pm 0.10 \pm 0.07 \text{ ps}^{-1}$.

LHCb, New J. Phys. 15, 053021 (2013) (1.0fb$^{-1}$); 
**CP Violation in \( B_s \) System**

- **The \( CP \)-violating phase \( \phi_s^{c\bar{c}s} \) in \( B_s \to J/\psi X \)**
  - Interference between w/ and w/o the mixing enables to access to the \( CP \)-violating phase.
  - \( \phi_s^{c\bar{c}s} = \phi_{\text{Mixing}} - 2\phi_{\text{Decay}} \)
    \( \phi_{\text{Decay}} \approx 0 \) (SM) \( \Rightarrow \phi_s^{c\bar{c}s} \approx \phi_{\text{Mixing}} \approx 0.04 \) (SM prediction).

- **Analysis method: similar to the \( \phi_1 \) case**
  - Reconstruct \( B_s \to J/\psi X \) candidate; tag the opposite \( B \)-meson flavor (\( B/\bar{B} \)); obtain decay length (typically \( \approx 1.5 \) mm) and convert it to decay time; obtain the \( \phi_s^{c\bar{c}s} \) by the maximum likelihood fit.
**CP Violation in \( B_s \) System**

- \( \phi_{s}^{c\bar{c}s} = +0.00 \pm 0.07 \) (HFAG winter-2014)
  - ATLAS (4.9 fb\(^{-1}\)): \( \phi_{s}^{J/\psi\phi} = -0.12 \pm 0.25 \pm 0.05 \text{ rad} \)
  - CMS (20 fb\(^{-1}\)): \( \phi_{s}^{J/\psi\phi} = -0.03 \pm 0.11 \pm 0.03 \text{ rad (new)} \)
  - LHCb (3.0 fb\(^{-1}\)): \( \phi_{s}^{J/\psi\pi\pi} = +70 \pm 68 \pm 8 \text{ mrad (updated)} \)
  - LHCb (1.0 fb\(^{-1}\)): \( \phi_{s}^{J/\psi\KK} = 0.07 \pm 0.09 \pm 0.01 \text{ rad (new)} \)
  - CDF (9.6 fb\(^{-1}\)): \( \phi_{s}^{J/\psi\pi\pi}: [-\pi/2, -1.51]\cup[-0.06, 0.30]\cup[1.26, \pi/2] \)
  - DØ (8 fb\(^{-1}\)): \( \phi_{s}^{J/\psi\phi} = -0.55^{+0.38}_{-0.36} \)

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**Data Plots**

- **LHCb preliminary**
  - \( B_d \)
  - \( B_s \)

- **CMS preliminary**
  - \( B_s \)

**Contour Plots**

- 68% CL contours
  - \( \Delta \log \mathcal{L} = 1.15 \)

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*References*

- CMS, CMS-PAS-BPH-13-012 (2014);
- LHCb, arXiv: 1405.4140 (2014);
- LHCb, PRD 87, 112010 (2014);
- CDF, PRL 109, 171802 (2012);
- DØ, PRD 85, 032006 (2012).
**CP Violation in $B_s$ System**

- $\phi_s \phi \phi = -0.17 \pm 0.12 \pm 0.04$ 
  
  - The $B_s \to \phi \phi$ is a pure-penguin mode with $b \to sq\bar{q}$.
  - The SM predicts $\phi_s \phi \phi = 0$ with low uncertainty.
  - Angular analysis of the $B_s \to K^+K^-K^+K^-$:
    - x3 $P$-wave amplitudes: $A_0, A_{ll}(CP$-even), and $A_{\perp}(CP$-odd)
    - x2 $S$-wave amplitudes: $A_5(\phi f_0 \ CP$-odd) and $A_{ss}(f_0 f_0 \ CP$-even)
  - Observed distributions of $\theta_1, \theta_2$, and $\Phi$ by the LHCb

B Factory Upgrade: Belle II/SuperKEKB

- NP signatures (deviation from the SM prediction) are expected very small at the B factory energy ($\sqrt{s}=11\text{GeV}$) → large number of events are needed to catch NP signatures.

- $x40$ luminosity, $L = 8.0 \times 10^{35}\text{cm}^{-2}\text{s}^{-1}$.

- More granular resolution.
- Faster signal output.
- Robustness to higher BG.

The SuperKEKB commissioning will start in 2015.
Belle II Detector in a Nutshell

- Central drift chamber with smaller cell size and longer lever arm
- Time of propagation counters
- Ring image Čerenkov counters
- Fast & high bandwidth data acquisition system
- Large scale mass storage system
- More elaborate hardware trigger
- 2-layer DEPFET pixel
- 4-layer DSSD
- Electromagnetic calorimeters
  - barrel: CsI(Tl)
  - endcap: pure CsI
- $K_{\ell}\mu$ detector
  - barrel: RPC
  - endcap: scintillator + SiPM
**CP Violation in** $B^0 \rightarrow K^0_s \pi^0 \gamma (b \rightarrow s \gamma)$

As a consequence, $B^0 \rightarrow K^0_s \pi^0 \gamma$ behaves like an effective flavor eigenstate, and mixing-induced CP violation is expected small:

$$S_{b \rightarrow s \gamma}^{\text{SM}} \equiv (\sin 2\phi_1) \times \left( -\frac{2m_s}{m_b} \right)$$

Analysis procedure is similar to that of $B^0 \rightarrow (c\bar{c})K^0$. 
**CP Violation in $B^0 \to K^0 s \pi^0 \gamma (b \to s \gamma)$**

\[ S_{b \to s \gamma}^{SM} \equiv (\sin 2\phi_1) \times \left( -\frac{2m_s}{m_b} \right) \]

\[ S_{b \to s \gamma}^{\text{average}} = -0.15 \pm 0.20 \]
(HFAG winter-2009)

\[ S_{b \to s \gamma}^{NP} \equiv +0.67 \]

A NP (left-right symmetric model) may enhance CP violation in this decay.

D. Atwood et al., PRL 79, 185 (1997).

**Prospect**

\[ \delta(S_{b \to s \gamma}) \sim 0.09 \at 5\text{ab}^{-1} \]
\[ \delta(S_{b \to s \gamma}) \sim 0.03 \at 50\text{ab}^{-1} \]
**CP Violation in $B^0 \rightarrow K^0_s \pi^0 \gamma (b \rightarrow s \gamma)$**


- **Detection of the NP effect in the $C_7'$**
  - The $C_7$ and $C_7'$ of the Wilson coefficients correspond to left- and right-handed EM penguin operator, respectively.
  - $C_7' \approx 0$ in the SM $\rightarrow C_7' \Rightarrow 0$ indicates the NP.
  - $Br(B \rightarrow X_s \gamma), S_{KS\pi^0\gamma},$ etc. give constraint on the $C_7$ and $C_7'$. Figures show the constraint in some extreme scenarios.

\[ C_7^{(NP)} = 0, \quad C_7'^{(NP)} \in \text{complex} \]

\[ C_7^{(NP)} = C_7'^{(NP)} \in \text{complex} \]

\[ C_7^{(NP)} = -C_7'^{(NP)} \in \text{complex} \]
Belle II Vertex Detector

• Precise measurement of $S_{KS\pi^0\gamma}$ demands precision vertex detection and high $K^0_S$ efficiency.
  – 2 layers of pixel detector
  + 4 layers of Si strip sensor array.

• System test at the DESY beam line in Jan. 2014
  – Good performance of the vertex detector is demonstrated together with its data acquisition system.
Kobayashi-Maskawa Unitarity

- Precise test of the Kobayashi-Maskawa unitarity

Combination of precise measurements on angles and sides of the unitarity triangle will test the unitarity of the Kobayashi-Maskawa matrix.

If unitarity is violated, 50ab⁻¹ data of the Belle II will reveal the violation, assuming the present values of the angles and sides are kept.
Summary

• Status of $CP$ violation measurements by Belle, BaBar, ATLAS, CMS, LHCb, CDF, and DØ are presented.
  – The unitarity triangle, $CP$ violation in the $b \rightarrow sq\bar{q}$, $K\pi$ puzzle, dimuon charge asymmetry, and $CP$ violation in the $B_s$ decay.

• Belle II, the upgraded B factory, is also summarized, together with some prospects for physics observables.

• SuperKEKB commissioning will start in 2015.
Backup Slides
**CP Violation in $b \rightarrow sq\bar{q}$ Transition**

Belle, PRD 90, 012002 (2014) (772M $B\bar{B}$).

- $B^0 \rightarrow \omega K^0$

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<td>+0.91±0.32±0.05</td>
<td>−0.36±0.19±0.15</td>
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<tr>
<td><strong>BaBar (467M $B\bar{B}$)</strong></td>
<td>+0.55$^{+0.26}_{-0.29}$±0.02</td>
<td>−0.52$^{+0.22}_{-0.20}$±0.03</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>0.71±0.21</td>
<td>−0.04±0.19±0.15</td>
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</table>

(HFAG winter-2014)

- The first evidence of the non-zero $-\xi_f S_f$ for the $B^0 \rightarrow \omega K^0$ is given.
Dimuon Charge Asymmetry

- **Dimuon charge asymmetry:** \( A_{CP} \equiv \frac{N_{ev}(\mu^+ \mu^+) - N_{ev}(\mu^- \mu^-)}{N_{ev}(\mu^+ \mu^+) + N_{ev}(\mu^- \mu^-)} \)

  - \( CP \) violation in mixing:
    \[ \Gamma(B_{(s)}^0 \rightarrow \bar{B}_{(s)}^0 \rightarrow \mu^- X) \neq \Gamma(B_{(s)}^0 \rightarrow B_{(s)}^0 \rightarrow \mu^+ X) \]

  - \( CP \) violation in interference between w/ and w/o the mixing:
    \[ \Gamma(B_{(s)}^0 \rightarrow \bar{B}_{(s)}^0 \rightarrow f_{CP}) \neq \Gamma(B_{(s)}^0 \rightarrow B_{(s)}^0 \rightarrow f_{CP}) \]
Dimuon Charge Asymmetry

- **SM prediction**
  - Dimuon charge asymmetry: \( A_{CP} = (-2.3^{+0.5}_{-0.6}) \times 10^{-4} \).

- **DØ measurement (single muon charge asymmetry)**
  - Test of the \( a_{CP} = 0 \) is a consistency check of the analysis procedure.

\[
a_{CP} \equiv \frac{n_{ev}(\mu^+) - n_{ev}(\mu^-)}{n_{ev}(\mu^+) + n_{ev}(\mu^-)}, \quad a_{CP}^{SM} \approx 10^{-5}
\]

\( a_{CP} = (-0.032 \pm 0.042 \pm 0.061)\% \), consistent with zero.

Events are categorized by \( p_T \), absolute value of the pesudorapidity, and impact parameter (integrated in the left figure) of the muon.
**Dimuon Charge Asymmetry**

- **DØ measurement (dimuon charge asymmetry)**

\[ A_{CP} = (-0.235 \pm 0.065 \pm 0.055)\% , \]

3.6σ deviation from the SM prediction.

All categories combined.

**Hint for the NP?**
SuperKEKB Accelerator in a Nutshell

\[ L = 8.0 \times 10^{35} / \text{cm}^2 \text{s} \]

Installation of new final focusing magnet
collision point resolution = 3mm

4.0GeV \( e^+ \)

4.0GeV \( e^- \) collision point

Improvements in beam pipe design

More RF cavities

Construction of damping ring
for low emittance \( e^+ \) beam
Belle II Vertex Detector

The very central part of the Belle II detector

- Silicon Vertex Detector (SVD): 4 layers of DSSDs
- Pixel Detector (PXD): 2 layers of DEPFET pixels

Pixel detector

Si strip sensor array
Belle II Vertex Detector

• A precision vertex detector is needed to measure the time-dependent $CP$-violating parameter $S_{KS\pi^0\gamma}$.
  
  – History
    • Belle (the 1st period): 3 layers of Si strip sensor array.
    • Belle (the 2nd period): 4 layers of Si strip sensor array.
    • Belle II: 2 layers of pixel detector + 4 layers of Si strip sensor array.
  
  – Improvement of the vertex resolution by a factor of $\sim 2$.
  
  – Improvement of the $K^0_S$ vertex resolution by a longer lever arm than the Belle.
**CP Violation Anomaly in B⁰/B⁺ Systems**

- **NP contribution**

  Contribution from $P_{EW}$ to the $B^+$ CP violation may be large due to a NP...

- **Check of the isospin sum rule**

  \[
  A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+) \frac{B(K^0\pi^+)}{B(K^0\pi^-)} \frac{\tau_0}{\tau_+} = A_{CP}(K^+\pi^0) \frac{2B(K^0\pi^0)}{B(K^+\pi^-)} \frac{\tau_0}{\tau_+} + A_{CP}(K^0\pi^0) \frac{2B(K^0\pi^0)}{B(K^+\pi^-)}
  \]

  Four CP-violating parameters in the $K\pi$ system are needed. That in the $K^0\pi^0$ is only possible with Super B factory statistics.  
  
  \[0.14 \pm 0.13 \pm 0.06 \text{ @ 600 fb}^{-1} \text{ (Belle)}\]

**Prospect** The sum rule can be checked with 10$ab^{-1}$ data
**CP Violation in $b \rightarrow sq\bar{q}$**

Measurement of the $CP$-violating parameter in $b \rightarrow sq\bar{q}$ is not expected to be systematic dominant until $50 ab^{-1}$ data with elaborated tunings of vertex detectors.

The Belle II may find a NP effect in the $b \rightarrow sq\bar{q}$ with $50 ab^{-1}$ data assuming the present discrepancy holds.

Prospect $\delta(S_{b \rightarrow s}) \sim 0.012 \; @ \; 50 ab^{-1}$
Why Do Expect NP in TeV Scale?

• Hierarchy problem
  – Standard-Model Higgs mass $m_H = 126 \text{ GeV/c}^2$, while because of a diagram shown below, the it will receive correction as $m_H^2 = (m_H^0)^2 + O(\Lambda^2)$, where $\Lambda$ is a scale of new physics.
  – If no new physics until the Planck scale $O(10^{18}\text{GeV/c}^2)$, $\Lambda$ and consequently $m_H$ will be $\sim O(10^{18}\text{GeV/c}^2)$ as well; we can expect $\Lambda < O(1\text{TeV/c}^2)$.
  – In SUSY words, the upper diagram is canceled by the lower one.
Complementarity (Belle II & LHCb)

**Energy frontier**

Direct detection of SUSY particles

Mass spectra are insufficient to figure out the SUSY model.

Similar mass spectra show up across different SUSY models.

**Luminosity frontier**

Measurements between SUSY-SUSY and/or SUSY-SM interactions

Various analyses on $B$, $\tau$, charm, ... decays enable to reveal the SUSY model.
Complementarity (Belle II & LHCb)

<table>
<thead>
<tr>
<th>Observable</th>
<th>SM prediction</th>
<th>Theory error</th>
<th>Present result</th>
<th>Future error</th>
<th>Future Facility</th>
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</thead>
<tbody>
<tr>
<td>$</td>
<td>V_{us}</td>
<td>$ [K → πν]$\ell$</td>
<td>input</td>
<td>0.5% → 0.1%$_{\text{Latt}}$</td>
<td>0.2246 ± 0.0012</td>
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<td>$</td>
<td>V_{cb}</td>
<td>$ [B → X_s(0)τ]</td>
<td>input</td>
<td>1%</td>
<td>$(41.54 ± 0.73) \times 10^{-3}$</td>
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<td>$</td>
<td>V_{ub}</td>
<td>$ [B → πν]$\ell$</td>
<td>input</td>
<td>10% → 5%$_{\text{Latt}}$</td>
<td>$(3.36 ± 0.36) \times 10^{-2}$</td>
</tr>
<tr>
<td>$\gamma$ [B → DK]$\ell$</td>
<td>input</td>
<td>&lt; 1°</td>
<td>$(70^{+27}_{-30})^{0}$</td>
<td>3°</td>
<td>LHCb</td>
</tr>
<tr>
<td>$S_{B_s\to\phi K}$</td>
<td>sin(2β)</td>
<td>≤ 0.01</td>
<td>0.671 ± 0.023</td>
<td>0.01</td>
<td>LHCb</td>
</tr>
<tr>
<td>$S_{B_s\to\phi\phi}$</td>
<td>0.036</td>
<td>≤ 0.01</td>
<td>0.81$^{+0.12}_{-0.32}$</td>
<td>0.01</td>
<td>LHCb</td>
</tr>
<tr>
<td>$S_{B_d\to\phi K}$</td>
<td>sin(2β)</td>
<td>≤ 0.05</td>
<td>0.44 ± 0.18</td>
<td>0.1</td>
<td>LHCb</td>
</tr>
<tr>
<td>$S_{B_d\to\phi\phi}$</td>
<td>0.036</td>
<td>≤ 0.05</td>
<td>—</td>
<td>0.05</td>
<td>LHCb</td>
</tr>
<tr>
<td>$S_{B_d\to K\gamma}$</td>
<td>few × 0.01</td>
<td>0.01</td>
<td>$-0.16 ± 0.22$</td>
<td>0.03</td>
<td>Super-B</td>
</tr>
<tr>
<td>$S_{B_s\to\phi\gamma}$</td>
<td>few × 0.01</td>
<td>0.01</td>
<td>—</td>
<td>0.05</td>
<td>LHCb</td>
</tr>
<tr>
<td>$A_{SL}^4$</td>
<td>$-5 \times 10^{-4}$</td>
<td>$10^{-4}$</td>
<td>$(5.8 ± 3.4) \times 10^{-3}$</td>
<td>$10^{-3}$</td>
<td>LHCb</td>
</tr>
<tr>
<td>$A_{SL}^8$</td>
<td>$2 \times 10^{-5}$</td>
<td>&lt; $10^{-5}$</td>
<td>$(1.6 ± 8.5) \times 10^{-3}$</td>
<td>$10^{-3}$</td>
<td>LHCb</td>
</tr>
<tr>
<td>$A_{CP}(B \to \phi\gamma)$</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>$-0.012 ± 0.028$</td>
<td>0.005</td>
<td>Super-B</td>
</tr>
<tr>
<td>$B(B \to \tau\nu)$</td>
<td>$1 \times 10^{-4}$</td>
<td>20% → 5%$_{\text{Latt}}$</td>
<td>$(1.73 ± 0.35) \times 10^{-4}$</td>
<td>5%</td>
<td>Super-B</td>
</tr>
<tr>
<td>$B(B \to \mu\nu)$</td>
<td>$4 \times 10^{-7}$</td>
<td>20% → 5%$_{\text{Latt}}$</td>
<td>&lt; $1.3 \times 10^{-6}$</td>
<td>6%</td>
<td>Super-B</td>
</tr>
<tr>
<td>$B(B_s \to \mu^+\mu^-)$</td>
<td>$3 \times 10^{-9}$</td>
<td>20% → 5%$_{\text{Latt}}$</td>
<td>&lt; $5 \times 10^{-8}$</td>
<td>10%</td>
<td>LHCb</td>
</tr>
<tr>
<td>$B(B_d \to \mu^+\mu^-)$</td>
<td>$1 \times 10^{-10}$</td>
<td>20% → 5%$_{\text{Latt}}$</td>
<td>&lt; $1.5 \times 10^{-8}$</td>
<td>[?]</td>
<td>LHCb</td>
</tr>
<tr>
<td>$A_{FB}(B \to K^+\mu^+\mu^-)_{\Sigma}$</td>
<td>0</td>
<td>0.05</td>
<td>$(0.2 ± 0.2)$</td>
<td>0.05</td>
<td>LHCb</td>
</tr>
<tr>
<td>$B \to K\nu\nu$</td>
<td>$4 \times 10^{-6}$</td>
<td>20% → 10%$_{\text{Latt}}$</td>
<td>&lt; $1.4 \times 10^{-5}$</td>
<td>20%</td>
<td>Super-B</td>
</tr>
<tr>
<td>$</td>
<td>q/P_D</td>
<td>$ missing</td>
<td>1</td>
<td>&lt; $10^{-3}$</td>
<td>$(0.80^{+0.18}_{-0.15})$</td>
</tr>
<tr>
<td>$\phi_D$</td>
<td>0</td>
<td>&lt; $10^{-3}$</td>
<td>$(0.6^{+0.3}_{-0.5})$</td>
<td>2°</td>
<td>Super-B</td>
</tr>
<tr>
<td>$B(K^+ \to \pi^+\nu\nu)$</td>
<td>$8.5 \times 10^{-11}$</td>
<td>8%</td>
<td>$(1.73^{+1.15}_{-1.05}) \times 10^{-10}$</td>
<td>10%</td>
<td>$K$ factory</td>
</tr>
<tr>
<td>$B(K^+ \to \pi^0\nu\nu)$</td>
<td>$2.6 \times 10^{-11}$</td>
<td>10%</td>
<td>&lt; $2.6 \times 10^{-8}$</td>
<td>[?]</td>
<td>$K$ factory</td>
</tr>
<tr>
<td>$R(\phi/\psi)(K \to \pi\nu\nu)$</td>
<td>$2.477 \times 10^{-5}$</td>
<td>0.04%</td>
<td>$(2.498 ± 0.014) \times 10^{-5}$</td>
<td>0.1%</td>
<td>$K$ factory</td>
</tr>
<tr>
<td>$B(t \to c\ell\gamma)$</td>
<td>$\mathcal{O}(10^{-13})$</td>
<td>$\mathcal{O}(10^{-13})$</td>
<td>&lt; $0.6 \times 10^{-2}$</td>
<td>$\mathcal{O}(10^{-5})$</td>
<td>LHCb (100 $fb^{-1}$)</td>
</tr>
</tbody>
</table>

### Belle II and LHCb

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Belle</th>
<th>Belle II</th>
<th>Belle II</th>
<th>LHCb</th>
</tr>
</thead>
<tbody>
<tr>
<td>~0.5ab⁻¹</td>
<td>5ab⁻¹</td>
<td>50ab⁻¹</td>
<td>10fb⁻¹ [5yrs]</td>
<td></td>
</tr>
<tr>
<td>(\Delta S(\phi K_S))</td>
<td>0.22</td>
<td>0.073</td>
<td>0.029</td>
<td>0.14</td>
</tr>
<tr>
<td>(\Delta S(\eta'K_S))</td>
<td>0.11</td>
<td>0.038</td>
<td>0.020</td>
<td>–</td>
</tr>
<tr>
<td>(\phi_s \text{ from } S(J/\psi\phi))</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>0.01</td>
</tr>
<tr>
<td>(S(K^*\gamma))</td>
<td>0.36</td>
<td>0.12</td>
<td>0.03</td>
<td>–</td>
</tr>
<tr>
<td>(S(\rho\gamma))</td>
<td>0.68</td>
<td>0.22</td>
<td>0.08</td>
<td>–</td>
</tr>
<tr>
<td>(\Delta Br/Br(B\to\tau\nu))</td>
<td>3.5σ</td>
<td>10%</td>
<td>3%</td>
<td>–</td>
</tr>
<tr>
<td>(Bs\to\mu\mu)</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>5σ @ 6 fb⁻¹</td>
</tr>
<tr>
<td>(\tau\to\mu\mu [x10^{-9}])</td>
<td>&lt;45</td>
<td>&lt;30</td>
<td>&lt;8</td>
<td>–</td>
</tr>
<tr>
<td>(\tau\to\mu\mu\mu [x10^{-9}])</td>
<td>&lt;209</td>
<td>&lt;10</td>
<td>&lt;1</td>
<td>–</td>
</tr>
<tr>
<td>(\phi_2)</td>
<td>11°</td>
<td>2°</td>
<td>1°</td>
<td>4.5°</td>
</tr>
<tr>
<td>(\phi_3)</td>
<td>16°</td>
<td>6°</td>
<td>2°</td>
<td>2.4°</td>
</tr>
</tbody>
</table>

- **Belle II and LHCb complementarily elucidate a NP.**
  - The Belle II can provide important physics relevant to the modes with \(\gamma, \pi^0, \nu, K_S^0, etc\ldots\) \((B\to\tau\nu, b\to sq\bar{q}, \tau \text{ LFV})...\).