Time dependent CP-violation in B decays at BELLE II

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on behalf of Belle II collaboration

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INFN Padova

FLASY 2018:
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Basel, 2-5 July 2018
Outline

1. Introduction
   - Unitary triangle
   - SuperKEKB and Belle II

2. Time Dependent CP Violation Measurements

3. $\phi_1/\beta$ measurement
   - $b \rightarrow c \bar{c} s$ transition
   - $b \rightarrow q \bar{q} s$ transition

4. $\phi_2/\alpha$ measurement
   - $B \rightarrow \pi \pi$
   - $B \rightarrow \rho \rho$

5. New Physics with TDCPV
   - $B^0 \rightarrow K_S^0 \pi^0 \gamma$

6. Conclusion and outlook
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Introduction

CPV

Why CP-Violation?

▶ Matter-Antimatter asymmetry in the universe.
▶ Sakharov’s 2\textsuperscript{nd} condition requires and CPV
▶ current known CPV in SM way smaller than needed.

$B^0$-system exhibits the largest CPV in the SM

CPV in SM is due to weak interaction and it is described by $V_{CKM}$ matrix

\[
\begin{bmatrix}
V_{ud} & V_{us} & V_{ub} \\
V_{cd} & V_{cs} & V_{cb} \\
V_{td} & V_{ts} & V_{tb}
\end{bmatrix}
= \begin{bmatrix}
1 - \frac{1}{2} \lambda & \lambda & A\lambda^3(\rho - i\eta) \\
-\lambda & 1 - \frac{1}{2} \lambda & A\lambda^2 \\
-A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1
\end{bmatrix} + \mathcal{O}(\lambda^4)
\]

Unitarity requires: \( \sum_k V_{ki}^* V_{kj} \) so

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

\( \mathcal{O}(\lambda^3) + \mathcal{O}(\lambda^3) + \mathcal{O}(\lambda^3) \)

main goal of Belle II is to precisely measure the CKM unitary triangle, and look for Beyond-SM physics using precision measurements at the intensity frontier.
CP Violation in $B$ meson systems

- Three angles ($\sim$ phases $\sim$ CPV) and three sides ($\sim$ Amplitudes $\sim$ BR):
  - $\phi_1 = \beta$: accessible via $B^0$ oscillation analysis $b \rightarrow c\bar{c}s$ and $b \rightarrow q\bar{q}s$
  - $\phi_2 = \alpha$: accessible via $B^0$ oscillation analysis $b \rightarrow u\bar{u}d$
  - $\phi_3 = \gamma$: relative phase of tree level $bc$ and $bu$ coupling;

- $\phi_{1,2}$ can be accessed via Time-Dependent CP Violation analysis of asymmetry in $B^0$ meson decay rate into CP eigenstate (TDCPV)

**Current world average**

- $\sin 2\beta_1 < 0.1$ (excl. at CL > 0.95)
- $\phi_2$ excluded area has CL > 0.95
- $\Delta m_3$ & $\Delta m_1$
- $|V_{ub}|$ & $|V_{cb}|$
- $\sin 2\beta_1$
- $\phi_3$
- $\Delta m_3$
- $\Delta m_1$
- $r_K$

**Excluded region**

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TDCPV at Belle II

Basel 2/7/2018 3 / 20
B-factories (BaBar @ SLAC and Belle @ KEKB): a 10 year long success:

- Asymmetric $e^- e^+ \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$
- collected together 1.5 ab$^{-1}$ of data in 1999 – 2010 (1 ab$^{-1}$ $\equiv$ $10 \times 10^9 B\bar{B}$)

- Discovery of CPV in B-system, indirect and direct;
- confirmation of CKM description of flavour phys;
- precision measurement of CKM elements;
- obs of several new hadronic states
- strong evidence of D meson mixing
Nano Beam scheme:

$\beta_y \sim \times 20$ smaller at IP

 Proposed by P. Raimondi for SuperB
Nano Beam is working!

Vertical beam size

Measured $z_0$ resolution

**Table**

<table>
<thead>
<tr>
<th></th>
<th>KEKB</th>
<th>SuperKEKB</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mathcal{L}$ ($10^{34} \frac{1}{s \cdot cm^2}$)</td>
<td>2.11</td>
<td>80 (x40)</td>
</tr>
<tr>
<td>$\int \mathcal{L} dt$ (ab$^{-1}$)</td>
<td>0.8</td>
<td>50</td>
</tr>
<tr>
<td>$e^-/e^+$ $E$ (GeV)</td>
<td>8/3.5</td>
<td>7/4</td>
</tr>
<tr>
<td>$e^-/e^+$ $I$ (A)</td>
<td>1.6/1.9</td>
<td>2.6/3.6 (x2)</td>
</tr>
<tr>
<td>$\beta\gamma$</td>
<td>0.45</td>
<td>0.28</td>
</tr>
<tr>
<td>$\langle \Delta z \rangle$ ($\mu m$)</td>
<td>$\sim 200$</td>
<td>$\sim 130$</td>
</tr>
</tbody>
</table>

Nano Beam scheme:

$\beta_y \sim x20$ smaller at IP

Proposed by P. Raimondi for SuperB
SuperKEKB

**Goal of Belle II/SuperKEKB**

- Integrated luminosity ($\int \mathcal{L} dt$ (ab$^{-1}$))
- Peak luminosity ($\mathcal{L}$ ($10^{34} \frac{1}{s \cdot cm^2}$))

<table>
<thead>
<tr>
<th>Calendar Year</th>
<th>KEKB</th>
<th>SuperKEKB</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017-2025</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- KEKB: $2.11 \times 10^{34}$ s$^{-1}$ cm$^{-2}$
- SuperKEKB: $80 \times 10^{34}$ s$^{-1}$ cm$^{-2}$ (x40)

- $\int \mathcal{L} dt$ (ab$^{-1}$) KEKB: 0.8
- SuperKEKB: 50

- $e^-/e^+ E$ (GeV) KEKB: 8/3.5
- SuperKEKB: 7/4

- $e^-/e^+ I$ (A) KEKB: 1.6/1.9
- SuperKEKB: 2.6/3.6 (x2)

- $\langle \Delta z \rangle$ (µm) KEKB: 0.45
- SuperKEKB: 0.28

**We are here**

**Vertex detector not yet installed, BEAST2 for background studies in place**

**Nano Beam scheme:**

- $\beta_y \sim x20$ smaller at IP

Proposed by P.Raimondi for SuperB
Belle II detector

**Challenges:**
- Much higher background wrt to KEKB
- Reduced CM boost wrt to Belle

**Improvement**
- New, extended vertex detector
  - 2 pixel layers: DEPFET technology
  - 4 layers of double sided Si microstrip sensors
- Smaller cell size and longer lever arm in CDC
- Improved electronic and light yield for EM calo
- New PID detector for K/π separation
- Better $K_S^0$ reconstruction
- Improved KLM ($K_L^0$, $\mu$) electronics

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

**Superconducting Magnet**
- homogeneous field of 1.5 T

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

**$K_L^0/\mu$ Detector**
- (outside)
- RPC-Plates and plastic scintillators with SiPM readout

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

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

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

**Aerogel RICH**
- Proximity focusing RICH with silica aerogel

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S. Lacaprara (INFN Padova)  TDCPV at Belle II  Basel 2/7/2018  6 / 20
Belle II: an improved detector

SVD and PXD

CDC

ARICH

ECL

TOP
Propaganda plot: It’s alive!

Record Lumi: $4.2 \cdot 10^{33} \frac{1}{s \cdot cm^2}$

26th April 2018, first hadronic event

Belle II

S.Lacaprara (INFN Padova)

[BELLE2-NOTE-PL-2018-016]

[BELLE2-NOTE-PL-2018-017]

[BELLE2-NOTE-PL-2018-014]
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Time Dependent $\mathcal{CP}$ Violation Measurements

Quantum entangled neutral $B$ meson pair production

- Precise measurement of the UT angles
- Look for new physics BSM if decay via loop (e.g., charmless)
- Possible with tree/penguin-dominated transitions:
  - $b \rightarrow c\bar{c}s$ ($B^0 \rightarrow J/\psi K^0$)
  - $b \rightarrow q\bar{q}s$ ($B^0 \rightarrow \eta' K^0, \phi K^0, \ldots$)
\[ P(\Delta t, q) = \frac{e^{-\Delta t/\tau_{B^0}}} {4\tau_{B^0}} \left[ 1 + q \left( A_{CP} \cos \Delta m_d \Delta t + S_{CP} \sin \Delta m_d \Delta t \right) \right] \]
Time Dependent $CP$ Violation Measurements

$$P(\Delta t, q) = e^{-\Delta t/\tau B^0} \left[ 1 + q(A_{CP} \cos \Delta m_d \Delta t + S_{CP} \sin \Delta m_d \Delta t) \right]$$

Quantum entangled neutral $B$ meson pair production

$B$ daughters

$B^0 (\bar{B}^0)$

$\Delta z = \Delta t \cdot \beta y c$

Fully reconstructed $CP$ eigenstate (e.g. $J/\psi K_S^0$)

Flavour tagging

Signal and Tag-side vertex resolution

Signal x feed Background ▶ Continuum ▶ Peaking

ML fit to extract the physical params

Toys to project sensitivity

Systematics (where dominant)
Time Dependent $\mathcal{CP}$ Violation Measurements

Quantum entangled neutral $B$ meson pair production

$e^+ e^- \rightarrow Y(4S)$

Fully reconstructed $\mathcal{CP}$ eigenstate (e.g. $J/\psi K_S$)

Flavour tagging $\beta \gamma = 0.28 (0.45)$

$\text{Belle2 (Belle)}$

$\beta \gamma = 0.28 (0.45)$

Signal and Tag-side vertex resolution

signal $\times$ feed

Background $\rightarrow$ Continuum $\rightarrow$ Peaking

$\text{ML fit to extract the physical params}$

Toys to project sensitivity $\ldots$ Systematics (where dominant)

proability parametrization vs $\Delta t$: $\mathcal{P}(\Delta t, q) = \frac{e^{-\Delta t/\tau_{B^0}}}{4\tau_{B^0}} \left[ 1 + q (A_{CP} \cos \Delta m_d \Delta t + S_{CP} \sin \Delta m_d \Delta t) \right]$
Time Dependent CP Violation Measurements

Quantum entangled neutral B meson pair production

Signal and Tag-side vertex resolution
Time Dependent $\mathcal{CP}$ Violation Measurements

\[ \mathcal{P}(\Delta t, q) = \frac{e^{-\Delta t/\tau_{B^0}}}{4\tau_{B^0}} [1 + q(A_{CP} \cos \Delta m_d \Delta t + S_{CP} \sin \Delta m_d \Delta t)] \]

- signal x feed
- Background
  - Continuum
  - Peaking
- ML fit to extract the physical params
- Toys to project sensitivity
- Systematics (where dominant)
- ...
Vertex resolution: on $B^0 \rightarrow J/\psi K_S^0$

Vertex fit: RAVE Adaptive Vertex Fit algo [CMS NOTE 2008/033]
down weights dynamically outliers (but those from $K_S^0$), no hard cut-off

$\Delta z$ resolution Tag-side $\Delta z$ resolution $J/\psi \rightarrow \mu\mu$ $\Delta t$ resolution

<table>
<thead>
<tr>
<th></th>
<th>Belle</th>
<th>Belle II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bias</td>
<td>29$\mu$m</td>
<td>6$\mu$m</td>
</tr>
<tr>
<td>Resolution</td>
<td>89$\mu$m</td>
<td>53$\mu$m</td>
</tr>
</tbody>
</table>

Better resolution in spite of reduced boost
Flavour tagger

Many different final states considered, combined with MVA method.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron</td>
<td>$e^+$</td>
</tr>
<tr>
<td>Int. Electron</td>
<td>$e^+$</td>
</tr>
<tr>
<td>Muon</td>
<td>$\mu^-$</td>
</tr>
<tr>
<td>Int. Muon</td>
<td>$\mu^+$</td>
</tr>
<tr>
<td>KinLepton</td>
<td>$l^-$</td>
</tr>
<tr>
<td>Int. KinLepton</td>
<td>$l^+$</td>
</tr>
<tr>
<td>Kaon</td>
<td>$K^-$</td>
</tr>
<tr>
<td>KaonPion</td>
<td>$K^-$, $\pi^+$</td>
</tr>
<tr>
<td>SlowPion</td>
<td>$\pi^+$</td>
</tr>
<tr>
<td>MaximumP*</td>
<td>$\pi^+$</td>
</tr>
<tr>
<td>FSC</td>
<td>$\pi^+$</td>
</tr>
<tr>
<td>FastPion</td>
<td>$\pi^+$</td>
</tr>
<tr>
<td>Lambda</td>
<td>$\Lambda$</td>
</tr>
</tbody>
</table>

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

$B^0 \rightarrow D^+ \pi^-$
$\rightarrow K^0 \nu_\ell \ell^+$

$B^0 \rightarrow A^+ X^-$
$\rightarrow \Lambda \pi^+$
$\rightarrow p \pi^-$

More than 10% efficiency increase on the same Belle dataset

**Belle II**
- Both
- $\bar{B}^0$
- $B^0$

**Belle Data - MC comparison of BII algo**
- Data
- MC

**effective efficiency**
- **Belle II MC** 37.16 ± 0.03%
- **Belle Data (assuming linearity)** 33.6 ± 0.5%
- **Belle MC** 34.18 ± 0.03%
- **Belle Data Old FT** 30.1 ± 0.4%
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\( \phi_1 \) in tree dominated \( b \to c\bar{c}s \) transitions: \( B^0 \to J/\psi K^0_S \)

Decay dominated by a single weak

phase small penguin pollution

\[ S \simeq \sin(2\phi_1) \]

Irreducible syst from vertex det alignment (two scenarios) & tag-side interference

Reducible systematics are expected to scale with luminosity (e.g. fit bias, signal fraction)

<table>
<thead>
<tr>
<th>Current status from Belle (^{[PRL 108 171802]})</th>
<th>Belle II expected uncertainties @ 50 ab(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>uncertainties ((10^{-3}))</td>
<td>Value</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>( J/\psi K^0_S )</td>
<td>( S )</td>
</tr>
<tr>
<td>( A \equiv -C )</td>
<td>-0.015</td>
</tr>
<tr>
<td>( b \to c\bar{c}s )</td>
<td>( S )</td>
</tr>
<tr>
<td>( A \equiv -C )</td>
<td>+0.006</td>
</tr>
</tbody>
</table>

Precision better than 1\% is expected on \( \phi_1 \) from \( b \to c\bar{c}s \)

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TDCPV at Belle II

Basel 2/7/2018 12 / 20
$\phi_1$ in penguin dominated $b \to q\bar{q}s$ transitions

Gluonic penguin dominates
almost same weak phase as $b \to c\bar{c}s$
not only penguin diagram present

Motivations:
- probes $\phi_1$ through different vertices;
- many different final states;
- more sensitive to new physics in the loop;
- tree/box pollution present but different predictions available

Current status:
All measurement are statistically limited

\[ \sin(2\beta_{\text{eff}}) \equiv \sin(2\phi_{\text{eff}}) \]

<table>
<thead>
<tr>
<th>Decay</th>
<th>Average</th>
<th>World Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b \to c\bar{c}s$</td>
<td>$0.69 \pm 0.02$</td>
<td></td>
</tr>
<tr>
<td>$\phi K^0$</td>
<td>$0.74 \pm 0.11$</td>
<td></td>
</tr>
<tr>
<td>$\eta' K^0$</td>
<td>$0.63 \pm 0.06$</td>
<td></td>
</tr>
<tr>
<td>$K_S K_S K_S$</td>
<td>$0.72 \pm 0.19$</td>
<td></td>
</tr>
<tr>
<td>$\pi^0 K^0$</td>
<td>$0.57 \pm 0.17$</td>
<td></td>
</tr>
<tr>
<td>$\rho^0 K_S$</td>
<td>$0.54 \pm 0.18$</td>
<td></td>
</tr>
<tr>
<td>$\omega K_S$</td>
<td>$0.71 \pm 0.21$</td>
<td></td>
</tr>
<tr>
<td>$f_2 K_S$</td>
<td>$0.69 \pm 0.10$</td>
<td></td>
</tr>
<tr>
<td>$f_3 K_S$</td>
<td>$0.48 \pm 0.53$</td>
<td></td>
</tr>
<tr>
<td>$f_4 K_S$</td>
<td>$0.20 \pm 0.53$</td>
<td></td>
</tr>
<tr>
<td>$\pi^0 \pi^0 K_S$</td>
<td>$-0.72 \pm 0.71$</td>
<td></td>
</tr>
<tr>
<td>$\phi \pi^0 K_S$</td>
<td>$0.97 \pm 0.52$</td>
<td></td>
</tr>
<tr>
<td>$\pi^0 \pi^0 K_S$</td>
<td>$0.01 \pm 0.33$</td>
<td></td>
</tr>
<tr>
<td>$K^0 K^0$</td>
<td>$0.68 \pm 0.09$</td>
<td></td>
</tr>
</tbody>
</table>
\[ b \rightarrow q\bar{q}s \text{ transitions: } B^0 \rightarrow \phi K^0 \text{ and } B^0 \rightarrow \eta'K^0 \]

- \( \phi K^0 \) ("an old superstar" A.J.Buras):
  - Ultimate sensitivity via Dalitz \( K^+K^-K^0 \) analysis.
  - For now: quasi-two body analysis:
  - \((\phi \rightarrow K^+K^-/\pi^+\pi^-\pi^0) + (K^0_S/K^0_L)\)
  - complication due to s-wave

\[ \text{WA } \sigma_S = 0.12, \sigma_C = 0.14 \]
\[ 5 \text{ ab}^{-1} \sigma_S = 0.048, \sigma_C = 0.035 \]
\[ 50 \text{ ab}^{-1} \sigma_S = 0.020, \sigma_C = 0.011 \text{ stat dominated} \]

- \( \eta'K^0 \):
  - different final states \( \eta' \rightarrow (\eta\gamma\gamma\pi^\pm, \eta_{3\pi}\pi^\pm, \rho\gamma) \), many neutrals, large cross-feed background

\[ \text{WA } \sigma_S = 0.06, \sigma_C = 0.04 \text{ (stat dominated)} \]
\[ 5 \text{ ab}^{-1} \sigma_S = 0.027, \sigma_C = 0.020 \]
\[ 50 \text{ ab}^{-1} \sigma_S = 0.015, \sigma_C = 0.008 \]

- \( \sigma_{\text{stat}} \sim \sigma_{\text{syst}} \) around \( \sim 10 - 20 \text{ ab}^{-1} \)

- competition with LHCb for \( K^0_S \), not for \( \eta'K^0 \)
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Two amplitudes of comparable size with different weak phase:

\[ \phi_2 / \alpha \text{ from } B^0 \rightarrow \pi\pi \]

Penguin in \( B^0 \rightarrow \pi^+ \pi^- , \pi^0 \pi^0 \), but not in \( B^\pm \rightarrow \pi^\pm \pi^0 \)

\[ \phi_2 = (\bar{A}^+ , A^0) , \quad \phi_{2eff} = (A^+ , \bar{A}^0) \]

Isospin analysis \cite{Gronau-London PRL, 64 3381 (1990)}: constraints

\( B^0 \) and \( B^\pm \) amplitudes:

\[ A^+ = A^+ / \sqrt{2} + A^0 \]
\[ \bar{A}^+ = \bar{A}^+ / \sqrt{2} + \bar{A}^0 \]
\[ |A^+| = |\bar{A}^+| \]

need to measure TDCPV all modes: \( \pi^+ , \pi^0 \)

- magnitude and phase of \( A^+ \) from \( B^0 \rightarrow \pi^+ \pi^- \);
- magnitude of \( A^0 \) from \( B \) and \( C_{00} \) of \( B^0 \rightarrow \pi^0 \pi^0 \)
  - no phase (\( S_{00} \)): triangles can flip
  - 8-fold ambiguity in \( \phi_2 (\alpha) \)
- need \( S_{00} \) (TDCPV) for \( B^0 \rightarrow \pi^0 \pi^0 \) to solve ambiguity.
Two amplitudes of comparable size with different weak phase:

Penguin in $B^0 \rightarrow \pi^+ \pi^-, \pi^0 \pi^0$, but not in $B^\pm \rightarrow \pi^\pm \pi^0$

$\phi_2 = (\bar{A}^{+0}, A^{+0}), \phi^{\text{eff}}_2 = (\bar{A}^{-+}, A^{-+})$

Isospin analysis: constraints

$B^0$ and $B^\pm$ amplitudes:

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

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

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

need to measure TDCPV all modes: $\pi^{+-}, \pi^{00}$

- magnitude and phase of $A$ from $B^0 \rightarrow \pi^+ \pi^-$;
- magnitude of $\bar{A}$ from $B$ and $C_{00}$ of $B^0 \rightarrow \pi^0 \pi^0$
  - no phase ($S_{00}$): triangles can flip
  - 8-fold ambiguity in $\phi_2(\alpha)$
- need $S_{00}$ (TDCPV) for $B^0 \rightarrow \pi^0 \pi^0$ to solve ambiguity.
First attempt to measure $S_{\pi^0\pi^0}$

<table>
<thead>
<tr>
<th>Final state</th>
<th>$BR(%)$</th>
<th>ev. yield for 50 ab$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^0\gamma(\rightarrow\gamma\gamma)$ $\pi^0\gamma(\rightarrow\gamma\gamma)$</td>
<td>98.823</td>
<td></td>
</tr>
<tr>
<td>$\pi^0_{dal}(\rightarrow e^+e^-\gamma)$ $\pi^0\gamma\gamma(\rightarrow\gamma\gamma)$</td>
<td>1.174</td>
<td>270</td>
</tr>
<tr>
<td>$\pi^0\gamma_c(\rightarrow\gamma_c\rightarrow e^+e^-\gamma)$ $\pi^0\gamma\gamma(\rightarrow\gamma\gamma)$</td>
<td>-</td>
<td>50</td>
</tr>
</tbody>
</table>

**Dalitz decay or conversion**

$\pi^0_{dal} \rightarrow e^+e^-\gamma$ and $B^0$ direction to reconstruct vertex

**$\Delta t$ resolution**

**Pure Dalitz**

$\delta(\Delta t) = 1.14 \pm 0.03$ ps

**Converted**

$\delta(\Delta t) = 1.42 \pm 0.04$ ps

Dalitz decays and $\gamma$ conversions reconstructed as Dalitz candidates can be separated on a statistical basis

Conversion vertices in the innermost part of detector
\( \phi_2/\alpha \) sensitivity from \( B^0 \rightarrow \pi\pi \\

- **Isospin analysis input in** \( B \rightarrow \pi\pi \)
  - current results (black line)
    - Belle \([\text{arXiv:1705.02083}] [\text{PRD 87(3) 031103}] [\text{PRD 88(9) 092003}]\)
    - Today \( \sigma_{\phi_2}^{\text{Belle exp}} = \pm 15^\circ \)
      - no results for \( S_{\pi^0\pi^0} \)
    - (WA including \( \pi\pi, \rho\rho, \rho\pi \): \( \sigma_{\phi_2}^{\text{WA exp}} = +4.4^\circ \))
  - expected results from Belle II with 50 ab\(^{-1}\) (blue area)
    - from improvement on already existing results
ϕ/α sensitivity from B⁰ → ππ

- **Isospin analysis input in B → ππ**
  - current results (black line)
    - Belle [arXiv:1705.02083][PRD 87(3) 031103][PRD 88(9) 092003]
    - Today $\sigma_{\phi_2}^{Belle} = \pm 15^\circ$
      - no results for $S_{\pi^0\pi^0}$
    - (WA including $\pi\pi$, $\rho\rho$, $\rho\pi$: $\sigma_{\phi_2}^{WA} = +4.4^\circ$)
  - expected results from Belle II with 50 ab⁻¹ (blue area)
    - from improvement on already existing results
  - Adding $S_{\pi^0\pi^0}$ input (color lines)
    - $\Delta \phi_{2,\pi\pi}^{exp} |^{88^\circ}_{1\sigma} \sim 2^\circ$
    - different solution depending on the actual value of $S_{\pi^0\pi^0}$
      - four different hypotesis shown

Belle, Belle II (+ $S_{\pi^0\pi^0}$)

<table>
<thead>
<tr>
<th>$1 - CL$</th>
<th>$\phi_2$ (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.83</td>
<td>30</td>
</tr>
<tr>
<td>0.40</td>
<td>60</td>
</tr>
<tr>
<td>-0.61</td>
<td>90</td>
</tr>
<tr>
<td>-0.94</td>
<td>120</td>
</tr>
</tbody>
</table>

S.Lacaprara (INFN Padova)
\( \phi_2/\alpha \) from \( B^0 \to \rho\rho \) and combined \( B^0 \to \pi\pi, \rho\rho \)

**Only \( B \to \rho\rho \)**

- Similar to \( B^0 \to \pi\pi \)
  - Only \( \rho_L \) to be used
  - \( S_{\rho_0\rho_0} \) available (BaBar\(^{[PRD78, 071104 (2008)]}\))
  - No ambiguity since \( B^0_{\rho_0\rho_0} \ll B^0_{\rho^+\rho^-} \)

\[
\sigma^{\rho\rho}_{\phi_2} \sim 0.7^\circ
\]

**Combining \( B \to \pi\pi \) and \( \rho\rho \)**

Combined: \( \sigma_{\phi_2}(\pi\pi, \rho\rho) \sim 0.6^\circ \)
Outline

1. Introduction
   - Unitary triangle
   - SuperKEKB and Belle II

2. Time Dependent CP Violation Measurements

3. $\phi_1/\beta$ measurement
   - $b \rightarrow c\bar{c}s$ transition
   - $b \rightarrow q\bar{q}s$ transition

4. $\phi_2/\alpha$ measurement
   - $B \rightarrow \pi\pi$
   - $B \rightarrow \rho\rho$

5. New Physics with TDCPV
   - $B^0 \rightarrow K_S^0\pi^0\gamma$

6. Conclusion and outlook
Motivation:

- $b \to s\gamma_R$ is helicity suppressed ($\frac{m_s}{m_b}$) wrt $b \to s\gamma_L$
- $B^0 \to f_{CP}\gamma_R$ interferes with $B^0 \to \bar{B}^0 \to f_{CP}\gamma_R$ only for helicity suppressed $b \to s\gamma_R$ decay
- TDCPV analysis is sensitive to the decay rate of $b$ into “wrongly” polarized $\gamma$.

- prediction:
  $$S^{SM}_{K^0_S\pi^0\gamma} \sim -2\frac{m_s}{m_b}\sin 2\phi_1 = -(2.3 \pm 1.6)\% \quad [\text{PRD75,054004(2007)}]$$
- current results: $S^{exp}_{K^0_S\pi^0\gamma} = -0.16 \pm 0.22 \quad [\text{HFLAV 2018}]$
- New physics can enhance the $b \to s\gamma_R$ decay rate

$K^*\gamma S_{CP} vs C_{CP}$

Contours give $-2\Delta(\ln L) = \Delta\chi^2 = 1$, corresponding to 39.3% CL for 2 dof

- BaBar ($N_{B\bar{B}} = 467 \cdot 10^6$) [PRD 78 (2008) 071102]
- Belle ($N_{B\bar{B}} = 535 \cdot 10^6$) [PRD 74 (2006) 111104(R)]
Probing New Physics with $b \to s\gamma$: $B^0 \to K_S^0\pi^0\gamma$

Motivation:

- $b \to s\gamma_R$ is helicity suppressed ($\frac{m_s}{m_b}$) wrt $b \to s\gamma_L$
- $B^0 \to f_{CP}\gamma_R$ interferes with $B^0 \to \bar{B}^0 \to f_{CP}\gamma_R$ only for helicity suppressed $b \to s\gamma_R$ decay
- TDCPV analysis is sensitive to the decay rate of $b$ into “wrongly” polarized $\gamma$.

Prediction:

- $S_{K_S^0\pi^0\gamma}^{SM} \sim -2\frac{m_s}{m_b}\sin 2\phi_1 = -(2.3 \pm 1.6)\%$ \cite{PRD75,054004(2007)}
- Current results: $S_{K_S^0\pi^0\gamma}^{exp} = -0.16 \pm 0.22$ \cite{HFLAV 2018}
- New physics can enhance the $b \to s\gamma_R$ decay rate
- Interesting at Belle II already with few $ab^{-1}$

$K^* \gamma S_{CP} \text{ vs } C_{CP}$

- BaBar ($N_{BB} = 467 \cdot 10^6$) \cite{PRD 78 (2008) 071102}
- Belle ($N_{BB} = 535 \cdot 10^6$) \cite{PRD 74 (2006) 111104(R)}
- Belle II: $L = 2, 10, 50 \text{ ab}^{-1}$
Outline

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   - Unitary triangle
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   - $B \rightarrow \pi\pi$
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6. Conclusion and outlook
Conclusion and outlook

- Belle II program at SuperKEKB
  - large dataset with an improved detector and algorithms.
  - unique possibilities for modes with final states with neutrals
    - complementary to LHCb
  - CKM will be measured and test at 1% level;
    \( \phi_1 = \beta \) will remain the most precisely measured angle (c\bar{c}s and \( q\bar{q}s \) modes);
    \( \phi_2 = \alpha \) will benefit from new input (\( S_{\pi_0\pi_0} \)) and reduced uncertainties;
    \( \phi_3 = \gamma \) will improve by \( \mathcal{O}(10) \), strong competition with LHCb;
    NP Probe for NP in TDCPV \( B^0 \rightarrow K_S^0\pi^0\gamma \)
  - More information on B2TIP report
Conclusion and outlook

Belle II program at SuperKEKB

- large dataset with an improved detector and algorithms.
- unique possibilities for modes with final states with neutrals
  - complementary to LHCb
- CKM will be measured and test at 1% level;
  \( \phi_1 = \beta \) will remain the most precisely measured angle (c\bar{c}s and \( q\bar{q}s \) modes);
  \( \phi_2 = \alpha \) will benefit from new input (\( S_{\pi^0 \pi^0} \)) and reduced uncertainties;
  \( \phi_3 = \gamma \) will improve by \( O(10) \), strong competition with LHCb;
- NP Probe for NP in TDCPV \( B^0 \rightarrow K_S^0 \pi^0 \gamma \)
- More information on B2TIP report
Conclusion and outlook

First SuperKEKB collision on April 26\textsuperscript{th}:
B $\bar{B}$ like event

B-factory are back in the game
Additional or backup slides

As requested, I fit my presentation on one PowerPoint slide.

I had to use all of the white space, but I think it was worth it to fit everything on one page.

It's actually only one bullet point, but it's a long one.
SuperKEKB is successor of former KEKB but refurbished with the new design.

“nano-beam” scheme
Beam squeezing: x20 smaller at IR

Luminosity = \( \frac{\gamma_{\pm}^2}{2er_e} \left( 1 + \frac{\sigma_y^*}{\sigma_x^*} \right) \frac{I_{\pm \gamma}^* R_L}{\beta_y^* R_y} \)

Target luminosity: \( 8 \times 10^{35} \text{cm}^{-2}\text{s}^{-1} \)
KEKB x 40!
SuperKEKB: new generation B-factory

Peak luminosity
- KEKB = 2.11x10^{34} \text{ cm}^{-2} \text{ s}^{-1}
- SuperKEKB = 8 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}

e^{-}e^{-} beams energy
- KEKB = 8 \text{ GeV} / 3.5 \text{ GeV}
- SuperKEKB = 7 \text{ GeV} / 4 \text{ GeV}

SuperKEKB Nanobeam
Phase 2 commissioning

- QCS magnet installed → first collision
- Full belle II detector without VXD (occupied by BEAST II)
- Tasks
  - Squeezing beta at IP, beam collision tuning and start physics data taking
  - Ensure safe background condition for VXD
  - Measure VXD occupancies
- To measure vertex detector in-situ occupancies, ladders are installed at horizontal plane (expect highest background level) of Belle II detector
- Plan to integrate 20 fb⁻¹
- Inst. Lumi.: $\mathcal{L}_{\text{Belle II}} \sim 40 \cdot \mathcal{L}_{\text{Belle}}$
- Background ↑↑↑
- Closest to IP
  - Occupancy ($\sim r^{-2}$) ↑↑↑
  - $\langle \beta \gamma \rangle_{\text{Belle II}} < \langle \beta \gamma \rangle_{\text{Belle}}$
  - smaller $\Delta z$
- Pixel Detector needed!
- DEPFET Technology most suited
- DEPlated Field Effect Transistor
$\sin(2\beta)$ in $b \rightarrow c\bar{c}s$ transitions

Systematics from Belle

<table>
<thead>
<tr>
<th></th>
<th>$J/\psi K_S^0$</th>
<th>$\psi(2S)K_S^0$</th>
<th>$\chi_c1 K_S^0$</th>
<th>$J/\psi K_L^0$</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vertexing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S_f$</td>
<td>$\pm 0.008$</td>
<td>$\pm 0.031$</td>
<td>$\pm 0.025$</td>
<td>$\pm 0.011$</td>
<td>$\pm 0.007$</td>
</tr>
<tr>
<td>$A_f$</td>
<td>$\pm 0.022$</td>
<td>$\pm 0.026$</td>
<td>$\pm 0.021$</td>
<td>$\pm 0.015$</td>
<td>$\pm 0.007$</td>
</tr>
<tr>
<td><strong>$\Delta t$</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S_f$</td>
<td>$\pm 0.007$</td>
<td>$\pm 0.007$</td>
<td>$\pm 0.005$</td>
<td>$\pm 0.007$</td>
<td>$\pm 0.007$</td>
</tr>
<tr>
<td>$A_f$</td>
<td>$\pm 0.004$</td>
<td>$\pm 0.003$</td>
<td>$\pm 0.004$</td>
<td>$\pm 0.003$</td>
<td>$\pm 0.001$</td>
</tr>
<tr>
<td><strong>Tag-side</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S_f$</td>
<td>$\pm 0.002$</td>
<td>$\pm 0.002$</td>
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</tr>
<tr>
<td>$A_f$</td>
<td>$+0.038$</td>
<td>$+0.038$</td>
<td>$+0.038$</td>
<td>$+0.000$</td>
<td>$+0.008$</td>
</tr>
<tr>
<td><strong>Flavor</strong></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>$S_f$</td>
<td>$\pm 0.003$</td>
<td>$\pm 0.003$</td>
<td>$\pm 0.004$</td>
<td>$\pm 0.003$</td>
<td>$\pm 0.004$</td>
</tr>
<tr>
<td>$A_f$</td>
<td>$\pm 0.003$</td>
<td>$\pm 0.003$</td>
<td>$\pm 0.003$</td>
<td>$\pm 0.003$</td>
<td>$\pm 0.003$</td>
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<tr>
<td><strong>Possible</strong></td>
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<tr>
<td>$S_f$</td>
<td>$\pm 0.004$</td>
<td>$\pm 0.004$</td>
<td>$\pm 0.004$</td>
<td>$\pm 0.004$</td>
<td>$\pm 0.004$</td>
</tr>
<tr>
<td>$A_f$</td>
<td>$\pm 0.005$</td>
<td>$\pm 0.005$</td>
<td>$\pm 0.005$</td>
<td>$\pm 0.005$</td>
<td>$\pm 0.005$</td>
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<tr>
<td><strong>Signal</strong></td>
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<td></td>
<td></td>
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<tr>
<td>$S_f$</td>
<td>$\pm 0.004$</td>
<td>$\pm 0.016$</td>
<td>$&lt; 0.001$</td>
<td>$\pm 0.016$</td>
<td>$\pm 0.004$</td>
</tr>
<tr>
<td>$A_f$</td>
<td>$\pm 0.002$</td>
<td>$\pm 0.006$</td>
<td>$&lt; 0.001$</td>
<td>$\pm 0.006$</td>
<td>$\pm 0.002$</td>
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<tr>
<td><strong>Background</strong></td>
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<td></td>
</tr>
<tr>
<td>$S_f$</td>
<td>$&lt; 0.001$</td>
<td>$\pm 0.002$</td>
<td>$\pm 0.030$</td>
<td>$\pm 0.002$</td>
<td>$\pm 0.001$</td>
</tr>
<tr>
<td>$A_f$</td>
<td>$&lt; 0.001$</td>
<td>$&lt; 0.001$</td>
<td>$&lt; 0.001$</td>
<td>$&lt; 0.001$</td>
<td>$&lt; 0.001$</td>
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<td><strong>Physics</strong></td>
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<td></td>
</tr>
<tr>
<td>$S_f$</td>
<td>$\pm 0.001$</td>
<td>$\pm 0.001$</td>
<td>$\pm 0.001$</td>
<td>$\pm 0.001$</td>
<td>$\pm 0.001$</td>
</tr>
<tr>
<td>$A_f$</td>
<td>$&lt; 0.001$</td>
<td>$&lt; 0.001$</td>
<td>$&lt; 0.001$</td>
<td>$&lt; 0.001$</td>
<td>$&lt; 0.001$</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S_f$</td>
<td>$\pm 0.013$</td>
<td>$\pm 0.036$</td>
<td>$\pm 0.040$</td>
<td>$\pm 0.021$</td>
<td>$\pm 0.012$</td>
</tr>
<tr>
<td>$A_f$</td>
<td>$+0.045$</td>
<td>$+0.047$</td>
<td>$+0.046$</td>
<td>$+0.017$</td>
<td>$+0.012$</td>
</tr>
</tbody>
</table>

Systematic errors in $S_f$ and $A_f \equiv C_f$ in each $f_{CP}$ mode and for the sum of all modes [PRL 108 171802]
b → q̅qs modes efficiencies

### Channel Strategy

<table>
<thead>
<tr>
<th>Channel</th>
<th>Strategy</th>
<th>(\varepsilon)</th>
<th>(\varepsilon_{SxF})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\eta'(\eta_\gamma\pi^\pm)K^{(\pm)}_S)</td>
<td>C*</td>
<td>23.0 %</td>
<td>3.8 %</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>6.7 %</td>
<td>2.6%</td>
</tr>
<tr>
<td></td>
<td>B*</td>
<td>8.0 %</td>
<td>6.0%</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>9.5 %</td>
<td>28.6%</td>
</tr>
</tbody>
</table>

Efficiency and fraction of cross feed candidates for \(\eta'(\eta_\gamma\pi^\pm)K^{(\pm)}_S\) and \(\eta'(\eta_3\pi\pi^\pm)K^{(\pm)}_S\) channels when selecting only one (A), two (B), or all (C) the candidates in the event. The selected strategy is labeled with *.

### Extrapolated sensitivity for the \(\omega K^0_S\) mode.

The \(\Delta t\) resolution is taken from the \(\eta' K^0_S\) study, while we assume a reconstruction efficiency of 21%

<table>
<thead>
<tr>
<th>(B^0 \rightarrow \omega K^0)</th>
<th>(\omega(\pi^+\pi^-\pi^0)K^0_S(\pi^\pm))</th>
<th>L (ab(^{-1}))</th>
<th>(\sigma(S))</th>
<th>(\sigma(A))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(L) (ab(^{-1}))</td>
<td>yield</td>
<td>(\sigma(S))</td>
<td>(\sigma(A))</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>334</td>
<td>0.17</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1670</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>16700</td>
<td>0.024</td>
<td>0.020</td>
</tr>
</tbody>
</table>

Sensitivity estimates for \(S_{\phi K^0}\) and \(A_{\phi K^0}\) parameters. The efficiency \(\varepsilon_{reco}\) used in this estimate has not been taken from the simulation, but is rather an estimate taking into account the expected improvements. Systematic uncertainties, negligible for these integrated luminosities, are not included.
**sin(2\(\beta\)) expected sensitivities**

<table>
<thead>
<tr>
<th>Channel</th>
<th>(\int \mathcal{L})</th>
<th>Event yield</th>
<th>(\sigma(S))</th>
<th>(\sigma(S)_{2017})</th>
<th>(\sigma(A))</th>
<th>(\sigma(A)_{2017})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(J/\psi K^0)</td>
<td>50 ab(^{-1})</td>
<td>1.4 \cdot 10^6</td>
<td>0.0052</td>
<td>0.022</td>
<td>0.0050</td>
<td>0.021</td>
</tr>
<tr>
<td>(\phi K^0)</td>
<td>5 ab(^{-1})</td>
<td>5590</td>
<td>0.048</td>
<td>0.12</td>
<td>0.035</td>
<td>0.14</td>
</tr>
<tr>
<td>(\eta' K^0)</td>
<td>5 ab(^{-1})</td>
<td>27200</td>
<td>0.027</td>
<td>0.06</td>
<td>0.020</td>
<td>0.04</td>
</tr>
<tr>
<td>(\omega K_S^0)</td>
<td>5 ab(^{-1})</td>
<td>1670</td>
<td>0.08</td>
<td>0.21</td>
<td>0.06</td>
<td>0.14</td>
</tr>
<tr>
<td>(K_S^0 \pi^0\gamma)</td>
<td>5 ab(^{-1})</td>
<td>1400</td>
<td>0.10</td>
<td>0.20</td>
<td>0.07</td>
<td>0.12</td>
</tr>
<tr>
<td>(K_S^0 \pi^0)</td>
<td>5 ab(^{-1})</td>
<td>5699</td>
<td>0.09</td>
<td>0.17</td>
<td>0.06</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Expected yields and uncertainties on the \(S\) and \(A\) parameters for the channels sensitive to \(\sin(2\phi_1)\) discussed in this chapter for an integrated luminosity of 50 (5) ab\(^{-1}\) for \(J/\psi K^0\) (penguin dominated modes). In the 5th and the last column are shown the present WA errors on each of the observables (HFAG summer 2016).
Likelihood fit

Multi dim. extended maximum likelihood fit to extract $S$ and $A$.

Pdf is of the form:

$$P^j_i = \mathcal{T}_j \left( \Delta t^i, \sigma^{i\Delta t}, \eta^{iCP} \right) \prod_k Q_{k,j}(x^i_k)$$

- **Time-dep part**
- **Time integrated**

Time-dependent part, taking into account mistag rate ($\eta_f = \pm 1$ is CP state):

$$f(\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau} \left\{ 1 \mp \Delta w \pm (1 - 2w) \times \left[ -\eta_f S_f \sin(\Delta m \Delta t) - A_f \cos(\Delta m \Delta t) \right] \right\}$$

Variables $(x^i_k)$ used, in addition to $\Delta t$

- $M_{bc}$
- $\Delta E$
- Cont. Suppr.
- SxF BDT/helicity angles

**Parameters:**

- Effective tagging efficiency: $Q = \epsilon (1 - 2w)^2 = 0.33$
  - $w = 0.21$, $\Delta w = 0.02$
- $\Delta t$ resolution (convoluted)
- $\tau$, $\Delta m$ from PDG
Isospin analysis input in $B \rightarrow \pi\pi$

<table>
<thead>
<tr>
<th>Value</th>
<th>Belle @ 0.8 ab$^{-1}$</th>
<th>Belle II @ 50 ab$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_{\pi^+\pi^-}$ [$10^{-6}$]</td>
<td>5.04 ±0.21 ±0.18 [2]</td>
<td>±0.03 ±0.08</td>
</tr>
<tr>
<td>$B_{\pi^0\pi^0}$ [$10^{-6}$]</td>
<td>1.31 ±0.19 ±0.18 [1]</td>
<td>±0.04 ±0.04</td>
</tr>
<tr>
<td>$B_{\pi^+\pi^0}$ [$10^{-6}$]</td>
<td>5.86 ±0.26 ±0.38 [2]</td>
<td>±0.03 ±0.09</td>
</tr>
<tr>
<td>$C_{\pi^+\pi^-}$</td>
<td>−0.33 ±0.06 ±0.03 [3]</td>
<td>±0.01 ±0.03</td>
</tr>
<tr>
<td>$S_{\pi^+\pi^-}$</td>
<td>−0.64 ±0.08 ±0.03 [3]</td>
<td>±0.01 ±0.01</td>
</tr>
<tr>
<td>$C_{\pi^0\pi^0}$</td>
<td>−0.14 ±0.36 ±0.12 [1]</td>
<td>±0.03 ±0.01</td>
</tr>
</tbody>
</table>

[1][arXiv:1705.02083], [2][PRD 87(3) 031103], [3][PRD 88(9) 092003]
Isospin analysis input in $B \to \pi\pi$

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>Belle @ 0.8 ab$^{-1}$</th>
<th>Belle II @ 50 ab$^{-1}$</th>
</tr>
</thead>
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<tr>
<td>$B_{\pi^+\pi^-}$ \ [10^{-6}]</td>
<td>5.04</td>
<td>$\pm 0.21 \pm 0.18$ [2]</td>
<td>$\pm 0.03 \pm 0.08$</td>
</tr>
<tr>
<td>$B_{\pi^0\pi^0}$ \ [10^{-6}]</td>
<td>1.31</td>
<td>$\pm 0.19 \pm 0.18$ [1]</td>
<td>$\pm 0.04 \pm 0.04$</td>
</tr>
<tr>
<td>$B_{\pi^+\pi^0}$ \ [10^{-6}]</td>
<td>5.86</td>
<td>$\pm 0.26 \pm 0.38$ [2]</td>
<td>$\pm 0.03 \pm 0.09$</td>
</tr>
<tr>
<td>$C_{\pi^+\pi^-}$</td>
<td>$-0.33$</td>
<td>$\pm 0.06 \pm 0.03$ [3]</td>
<td>$\pm 0.01 \pm 0.03$</td>
</tr>
<tr>
<td>$S_{\pi^+\pi^-}$</td>
<td>$-0.64$</td>
<td>$\pm 0.08 \pm 0.03$ [3]</td>
<td>$\pm 0.01 \pm 0.01$</td>
</tr>
<tr>
<td>$C_{\pi^0\pi^0}$</td>
<td>$-0.14$</td>
<td>$\pm 0.36 \pm 0.12$ [1]</td>
<td>$\pm 0.03 \pm 0.01$</td>
</tr>
<tr>
<td>$S_{\pi^0\pi^0}$</td>
<td>—</td>
<td>—</td>
<td>$\pm 0.29 \pm 0.03$</td>
</tr>
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</table>

[1][arXiv:1705.02083], [2][PRD 87(3) 031103], [3][PRD 88(9) 092003]

Adding $S_{\pi^0\pi^0}$ input

$\Delta \phi_{exp}^{\pi\pi|^{88^\circ}} \sim 2^\circ$

Today $\sigma_{WA}^{exp}=+4.4^\circ$, $\sigma_{Belle}^{exp}=\pm 15^\circ$
\[ \phi_2/\alpha \text{ from } B^0 \rightarrow \rho \rho \]

Similar to \( B^0 \rightarrow \pi\pi \): only \( \rho_L \) to be used, \( S_{\rho_0\rho_0} \) available (BaBar\cite{4})

No ambiguity since \( B_{\rho^0\rho^0} \ll B_{\rho^+\rho^-} \)

<table>
<thead>
<tr>
<th>Value</th>
<th>0.8 ab(^{-1})</th>
<th>50 ab(^{-1})</th>
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<tbody>
<tr>
<td>( f_{L,\rho^+\rho^-} )</td>
<td>0.988 ± 0.012 ± 0.023 [1]</td>
<td>± 0.002 ± 0.003</td>
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<tr>
<td>( f_{L,\rho^0\rho^0} )</td>
<td>0.21 ± 0.20 ± 0.15 [2]</td>
<td>± 0.03 ± 0.02</td>
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<tr>
<td>( B_{\rho^+\rho^-} ) [10^{-6}]</td>
<td>28.3 ± 1.5 ± 1.5 [1]</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 [2]</td>
<td>± 0.04 ± 0.02</td>
</tr>
<tr>
<td>( A_{\rho^+\rho^-} )</td>
<td>0.00 ± 0.10 ± 0.06 [1]</td>
<td>± 0.01 ± 0.01</td>
</tr>
<tr>
<td>( S_{\rho^+\rho^-} )</td>
<td>−0.13 ± 0.15 ± 0.05 [1]</td>
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<td>( f_{L,\rho^0\rho^0} )</td>
<td>0.95 ± 0.11 ± 0.02 [3]</td>
<td>± 0.004 ± 0.003</td>
</tr>
<tr>
<td>( B_{\rho^0\rho^0} ) [10^{-6}]</td>
<td>31.7 ± 7.1 ± 5.3 [3]</td>
<td>± 0.3 ± 0.5</td>
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<td>( A_{\rho^0\rho^0} )</td>
<td>−0.2 ± 0.8 ± 0.3 [4]</td>
<td>± 0.08 ± 0.01</td>
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<tr>
<td>( S_{\rho^0\rho^0} )</td>
<td>0.3 ± 0.7 ± 0.2 [4]</td>
<td>± 0.07 ± 0.01</td>
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\[ \sigma_{\phi_2}^{\rho\rho} \sim 0.7^\circ (\; \text{WA} \pm 5^\circ) \]

Combined: \( \sigma_{\phi_2}^{\pi\pi, \rho\rho} \sim 0.6^\circ \)
\( \phi_2 \) from isospin analysis \( B^0 \rightarrow \rho \rho, B^0 \rightarrow \rho \pi \),

Similar to \( B^0 \rightarrow \pi \pi \), larger \( B \) and \( \varepsilon \): only \( \rho_L \) to be used, \( S_{\rho_0 \rho_0} \) available (BaBar). \( \sigma_{\phi_2} \sim 5^\circ \)

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<tr>
<td>( f_{L,\rho^+ \rho^-} )</td>
<td>0.988</td>
<td>( \pm 0.012 \pm 0.023 ) [77]</td>
<td>( \pm 0.002 \pm 0.003 )</td>
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<tr>
<td>( f_{L,\rho^0 \rho^0} )</td>
<td>0.21</td>
<td>( \pm 0.20 \pm 0.15 ) [83]</td>
<td>( \pm 0.03 \pm 0.02 )</td>
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<tr>
<td>( B_{\rho^+ \rho^-} ) ([10^{-6}])</td>
<td>28.3</td>
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<td>( f_{L,\rho^+ \rho^0} )</td>
<td>0.95</td>
<td>( \pm 0.11 \pm 0.02 ) [68]</td>
<td>( \pm 0.004 \pm 0.003 )</td>
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<td>31.7</td>
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<tr>
<td>( C_{\rho^0 \rho^0} )</td>
<td>0.2</td>
<td>( \pm 0.8 \pm 0.3 ) [67]</td>
<td>( \pm 0.08 \pm 0.01 )</td>
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<tr>
<td>( S_{\rho^0 \rho^0} )</td>
<td>0.3</td>
<td>( \pm 0.7 \pm 0.2 ) [67]</td>
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\( \sigma_{S_{00}} C_{00} \sim 0.2 \) with 5 ab\(^{-1}\)

also improv. on \( f_L B(B^0 \rightarrow \rho^+ \rho^-) \) and \( f_L B(B^+ \rightarrow \rho^+ \rho^0) \) useful With 50 ab\(^{-1}\) \( \sigma_{\phi_2} \sim 2.5^\circ \)

\( B^0 \rightarrow \rho \pi \)

- Analysis done with Dalitz plot on \( \pi^+ \pi^- \pi^0 \) final state.
- current analyses by BaBar and Belle suffer from low statistics
- which cause secondary solutions for \( \phi_2 \) on both sides of primary
- and expected to vanish with larger dataset
- Strong motivation to repeat the analysis with at least few ab\(^{-1}\)
- No prediction available
Competition with LHCb: luminosity
$B \rightarrow \rho \rho$

$\phi_3/\gamma$ measurement

- $B \rightarrow D(K_0^0\pi^+\pi^-)K^\pm$
- $V_{ub}$
**\( \phi_3/\gamma \) measurement**

- \( \phi_3/\gamma \) is the phase between \( b \to c \) and \( b \to u \)
- from interference of tree-level diagrams
  - ✓ no B mixing, nor penguin pollution
  - ✖ theoretical ambiguity very small
  - ✗ different strong phase
  - ✡ today CLEO-c results [PRD82, 112006 (2010)]
  - ✡ improvement from BESIII (10 fb\(^{-1}\) @\( \psi(3770) \))

\[ B^\pm \to D[\to K_S^{0} \pi^+ \pi^-]K^\pm \]

- Golden mode for Belle II;
- large \( B \), good \( K_S^0 \) reconstruction
- self conjugate \( D \to K_S^{0} \pi^+ \pi^- \) decay
- binned Dalitz plot analysis of \( D \to K_S^{0} \pi^+ \pi^- \) decay (GGSZ) [PRD68, 054018 (2003)]

---

**Interference if \( D/\overline{D} \to f \) same final state**

![Diagram showing interference](image-url)
Current status:

\[ \phi_3^Belle = \left( 78^{+15}_{-16} \right)^\circ \quad \phi_3^{LHCb} = \left( 76.8^{+5.1}_{-5.7} \right)^\circ \]

- sensitivity study on GGSZ $B^\pm \rightarrow D[\rightarrow K_S^0 \pi \mu]\]K^\pm$
  - expected sensitivity to $\phi_3 \sim 3^\circ$ with $50 \text{ ab}^{-1}$
- improvement including:
  - GGSZ $D \rightarrow K_S^0 K_\pm K^- \pm$ and $B^\pm \rightarrow D^* K^\pm$
  - ADS/GLW modes $B^\pm \rightarrow D^*[\rightarrow D \gamma \pi^0]K^\pm$
- LHCb will dominate with charged final state;
- further improvement with final states with neutrals and significant $B$;
  - CP-even $\pi^0 \pi^0$, $K_L^0 \pi^0$, $K_S^0 \pi^0 \pi^0$, $K_S^0 \eta \pi^0$, $K_S^0 K_S^0 K_S^0$;
  - CP-odd $K_S^0 K_S^0 K_L^0$, $\eta \pi^0 \pi^0$, $\eta' \pi^0 \pi^0$, $K_S^0 K_S^0 \pi^0$, $K_S^0 K_S^0 \eta$;
  - Self-conjugate $K_L^0 \pi^0 \pi^0$, $K_L^0 K^+ K^-$, $K_S^0 \pi^0 \pi^0$, $\pi^+ \pi^- \pi^0 \pi^0$.

Projected $\phi_3$ sensitivity for different luminosity profile scenarios
Competition with LHCb: $\phi_3$
Competition with LHCb: Direct CPV
$|V_{ub}|$ can be measured via exclusive or inclusive semileptonic B decay.

Long standing $3\sigma$ tension between the two measurements

$|V_{ub}^{\text{excl}}| = (3.67 \pm 0.09(\text{exp}) \pm 0.12(\text{theo})) \times 10^{-3}$ vs $|V_{ub}^{\text{incl}}| = (4.52 \pm 0.15(\text{exp}) \pm 0.11(\text{theo})) \times 10^{-3}$

**Exclusive**

- Most promising channel is $B \to \pi \ell \nu$

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

- $f_{B\pi}$ form factor (theo) limits precision
  - **Tagged**: fully reconstruct B companion, good $q^2$ resolution, low $\varepsilon \sim 0.55\%(0.3\%\text{Belle})$
  - Expected precision 1.3%

- **Untagged**: indirect determination of B companion: bad $q^2$ resolution, good $\varepsilon \sim 20\%(11\%\text{Belle})$
  - Expected precision 1.7%

**Inclusive**

- From measurement of total or partial inclusive semileptonic branching decay rate $b \to u \ell \nu$

- Fully rec tag-side, $\ell$ in signal side

- Fit $B \to X_u \ell \nu$ rates with model from simulation
  - Limiting factor is modelling the dynamic of the decaying $b$ quark
  - Using $B \to X_s \gamma$ to study dynamic

- Expected precision: $3.4(3)\% \ @5(50) \ ab^{-1}$
Competition with LHCb: $V_{ub}$