

Current Status for *CP* Violation Measurements

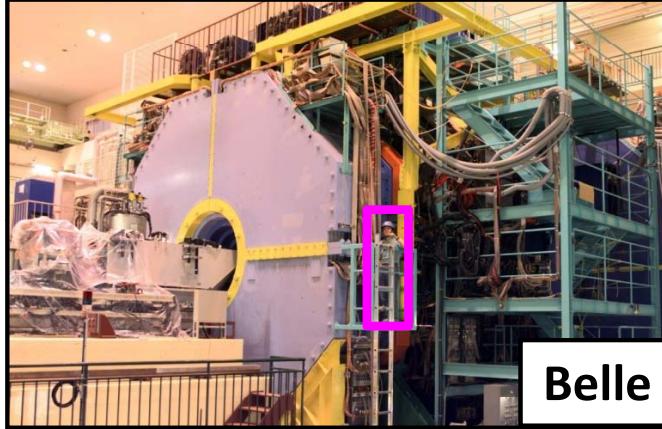
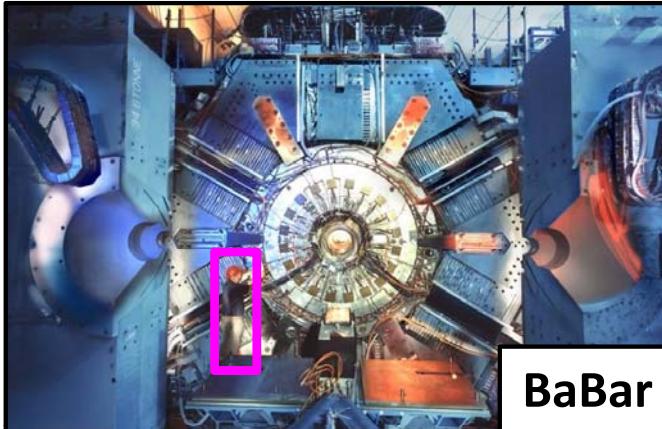
Takeo Higuchi

Kavli IPMU, the University of Tokyo (WPI)

the Belle collaboration

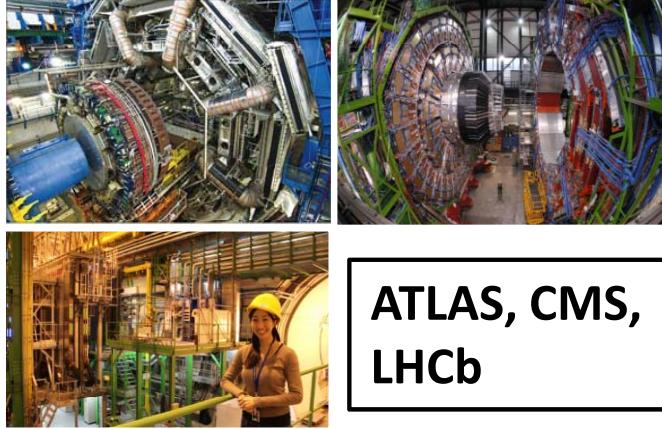
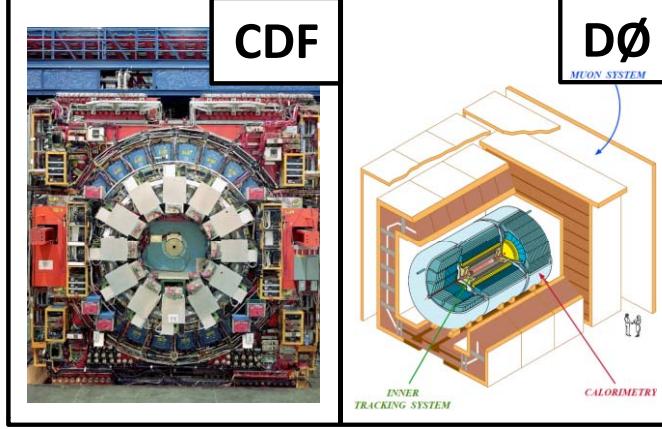
the Belle II collaboration

Belle/KEKB, BaBar/PEP-II

	Accelerator	Detector	$\int L dt$
Belle	 KEKB	 Belle	1052 fb^{-1}
BaBar	 PEP-II	 BaBar	558 fb^{-1}

“The Physics of B Factories” Book jointly accomplished
by Belle and BaBar (arXiv:1406.6311, to be published in EPJC).

LHC; DØ+CDF/Tevatron

	Accelerator	Detector	$\int L dt$
ATLAS CMS LHCb		 <div style="border: 1px solid black; padding: 5px; display: inline-block;"> ATLAS, CMS, LHCb </div>	
DØ CDF			$\sim 11 \text{ fb}^{-1}$

Unitarity Triangle

- $\Phi_1 = (21.50^{+0.75}_{-0.74})^0$ (CKMfitter winter-2014)
 - $S_{c\bar{c}s} (\sin 2\Phi_1) = 0.682 \pm 0.019$ (HFAG winter-2014)
 - Belle (772M $B\bar{B}$ at $\Upsilon(4S)$): $0.667 \pm 0.023 \pm 0.012$
 - BaBar (465M $B\bar{B}$ $\Upsilon(4S)$): $0.687 \pm 0.028 \pm 0.012$
 - Belle (121fb^{-1} at $\Upsilon(5S) \rightarrow B^0 B^+ \pi^-$): $0.57 \pm 0.58 \pm 0.06$
 - 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 (Δt).
 - LHCb: absolute decay time of the B meson (t).

Belle, PRL 108, 171802 (2012);
BaBar, PRD 79, 072009 (2009);
Belle, PRL 108, 171801 (2012);
LHCb, PLB 721, 24 (2013).

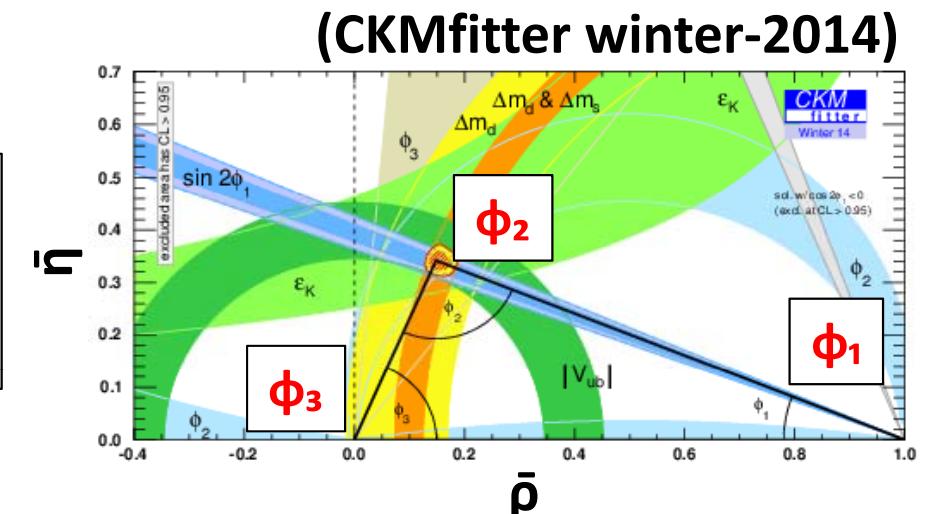
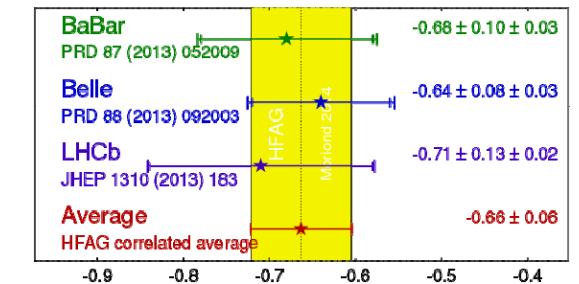
Unitarity Triangle

- $\Phi_2 = (85.4^{+4.0}_{-3.9})^0$ (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 $\Upsilon(4S)$): $-0.64 \pm 0.08 \pm 0.03$
 - BaBar (467M $B\bar{B}$ $\Upsilon(4S)$): $-0.68 \pm 0.10 \pm 0.03$
 - 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)
 - $\sigma_{\sin 2\phi_1} = 1.96$
 - $\sigma_{\phi_2} = 1.56$
 - $\sigma_{\phi_3} = 0.41$

*Tensions between
direct and indirect
measurements.*

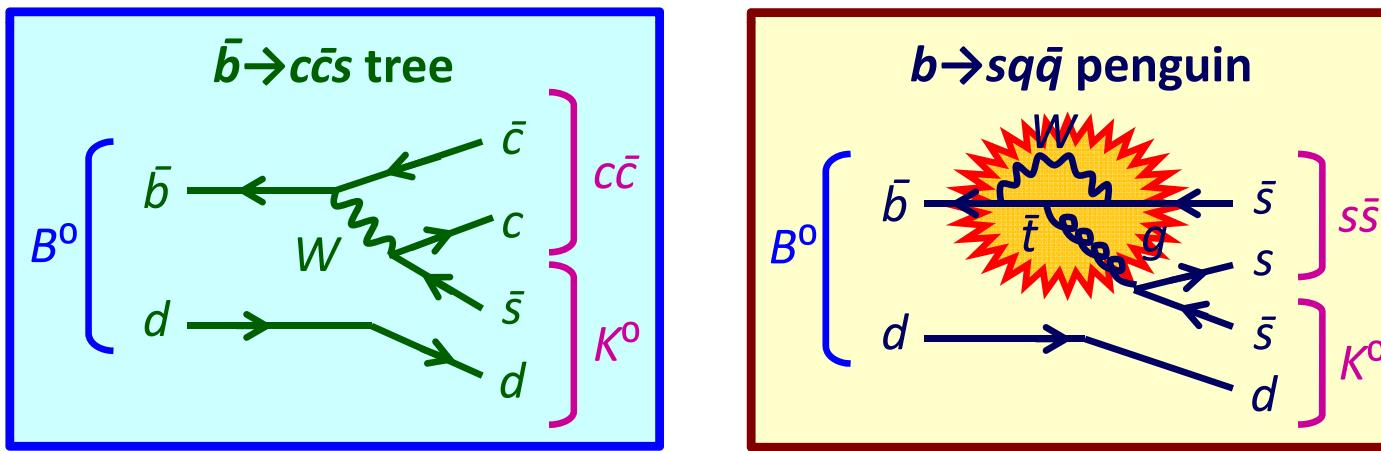
Belle, PRD 88, 092003 (2013);
BaBar, PRD 87, 052009 (2013);
LHCb, JHEP 1310, 183 (2013).

HFAG
Moriond 2014
PRELIMINARY



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 $O(0.01\text{--}0.1)$ will indicate the NP.

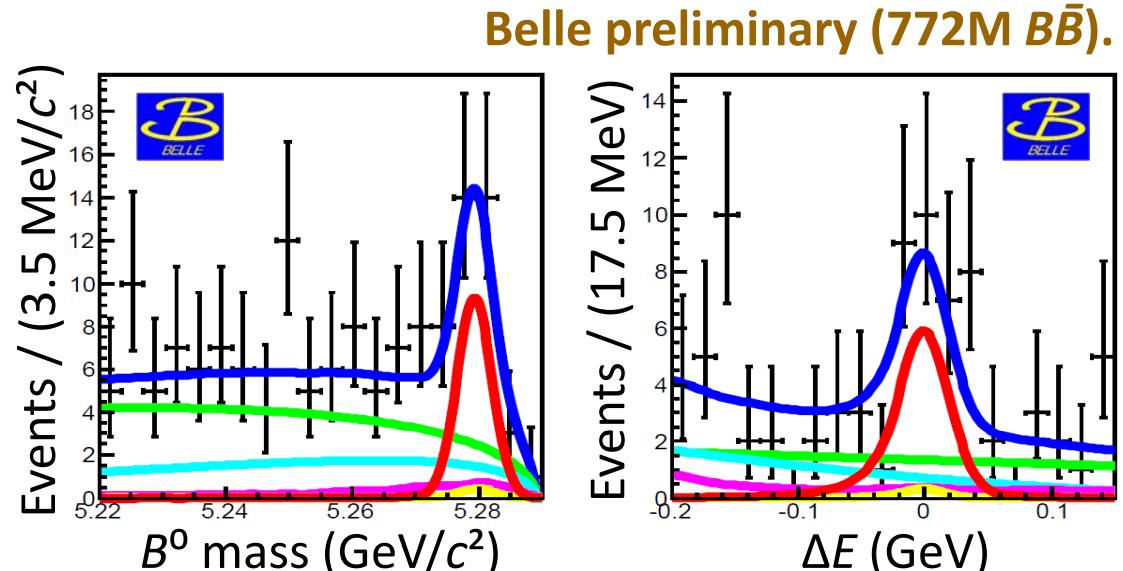
CP Violation in $b \rightarrow sq\bar{q}$ Transition

- $B^0 \rightarrow \eta' K^{*0}$
 $(K^{*0} \rightarrow K^+ \pi^-, \eta' \rightarrow \eta \pi \pi)$
 - 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 5σ measurement.**

- The direct CP -violating parameter is determined as well:

$$A_{CP}(\eta' K^{*0}) = \frac{\Gamma(\bar{B}^0 \rightarrow \eta' K^- \pi^+) - \Gamma(B^0 \rightarrow \eta' K^+ \pi^-)}{\Gamma(\bar{B}^0 \rightarrow \eta' K^- \pi^+) + \Gamma(B^0 \rightarrow \eta' K^+ \pi^-)} = (-0.22 \pm 0.29 \pm 0.07)$$



Beam energy constrained B^0 mass, and energy difference of the reconstructed B^0 from the expected one.

Signal, $q\bar{q}$ BG, generic- B -decay BG, etc.

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

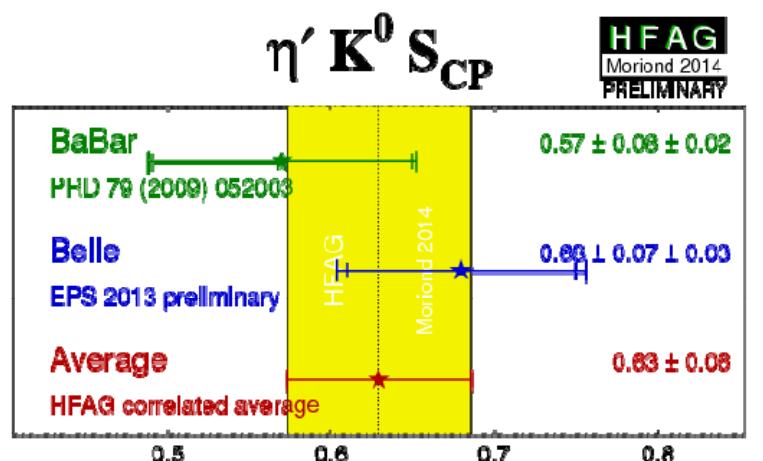
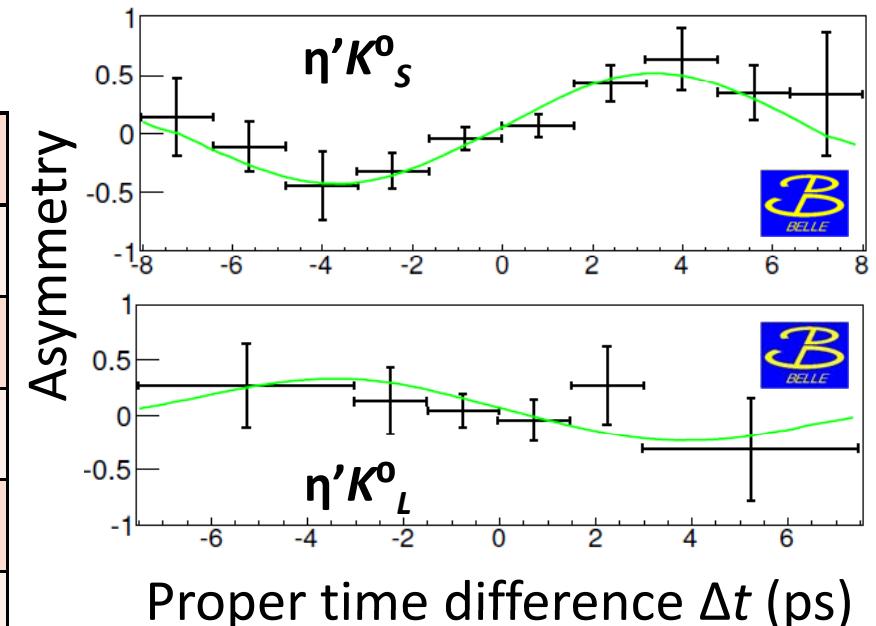
- $B^0 \rightarrow \eta' K^0$ ($\eta' \rightarrow \rho\gamma, \eta\pi\pi$)

(HFAG winter-2014)

Belle	$-\xi_f S_f$	$+0.68 \pm 0.07 \pm 0.03$
	A_f	$+0.03 \pm 0.05 \pm 0.04$
BaBar	$-\xi_f S_f$	$+0.57 \pm 0.08 \pm 0.02$
	A_f	$+0.08 \pm 0.06 \pm 0.02$
Average	$-\xi_f S_f$	$+0.63 \pm 0.06$
	A_f	$+0.05 \pm 0.04$

- 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 $B\bar{B}$).



$K\pi$ Puzzle in $B \rightarrow K\pi$

- The $K\pi$ puzzle in $B \rightarrow K\pi$

Belle	$A_{CP}(K^+\pi^-)$	$-0.069 \pm 0.014 \pm 0.014$
	$A_{CP}(K^+\pi^0)$	$+0.043 \pm 0.024 \pm 0.002$
BaBar	$A_{CP}(K^+\pi^-)$	$-0.107 \pm 0.016^{+0.006}_{-0.004}$
	$A_{CP}(K^+\pi^0)$	$+0.030 \pm 0.039 \pm 0.010$

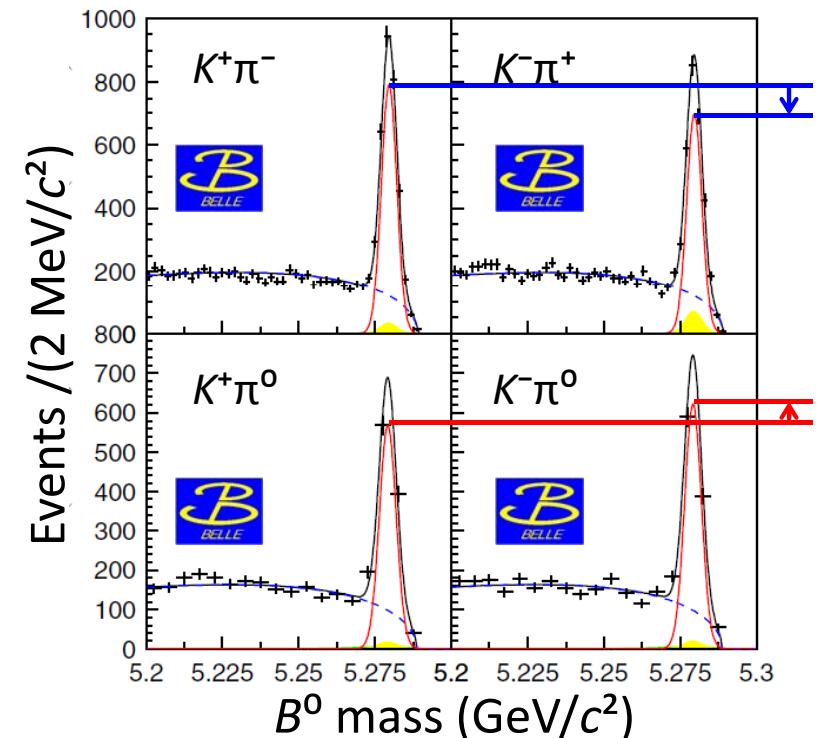
Non-zero $[A_{CP}(K^+\pi^-) - A_{CP}(K^+\pi^0)]$ indicates the effect of color-suppressed EW penguin amplitudes are significant.

- The isospin sum rule

$$\mathcal{A}_{CP}(K^+\pi^-) + \mathcal{A}_{CP}(K^0\pi^+) \frac{\mathcal{B}(K^0\pi^+) \tau_0}{\mathcal{B}(K^+\pi^-) \tau_+} = \mathcal{A}_{CP}(K^+\pi^0) \frac{2\mathcal{B}(K^+\pi^0) \tau_0}{\mathcal{B}(K^+\pi^-) \tau_+} + \mathcal{A}_{CP}(K^0\pi^0) \frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

- NP contribution can be probed via the sum rule violation.
- Present deviation = 1.9σ (Belle).

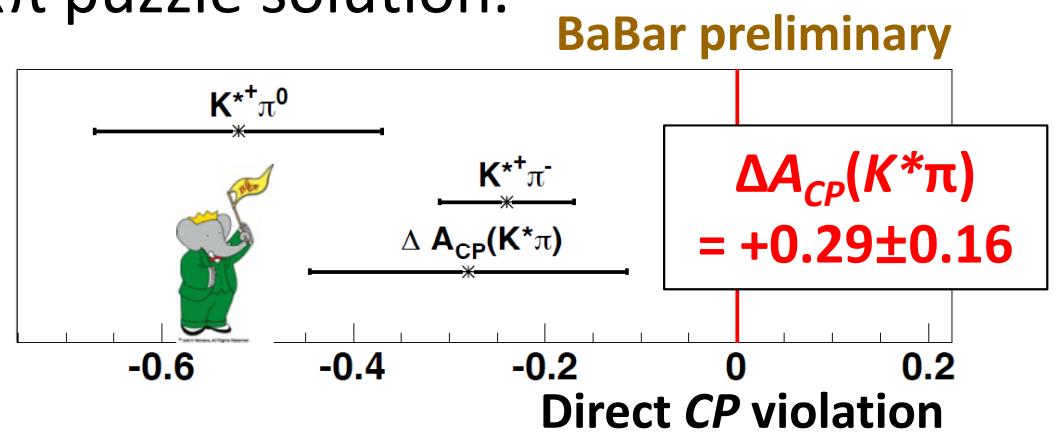
Belle, PRD 87, 031103(R) (2013) (772M $B\bar{B}$);
 BaBar, PRD 76, 091102(R) (2007) (383M $B\bar{B}$);
 BaBar, PRD 87, 052009 (2013) (467M $B\bar{B}$).



$K\pi$ Puzzle in $B \rightarrow K^*\pi$

- **$K\pi$ puzzle in $B \rightarrow K^*\pi$**
 - The direct CP violation measurement in $B \rightarrow K^*\pi$ can be another approach to the $K\pi$ puzzle solution.

Decay	Direct CP violation
$K^0\pi^+\pi^0$	$0.07 \pm 0.05 \pm 0.03 \pm 0.04$
$K^{*0}(892)\pi^+$	$-0.12 \pm 0.21 \pm 0.08 \pm 0.11$
$K^{*+}(892)\pi^0$	$-0.52 \pm 0.14 \pm 0.04 \pm 0.04$
$K_0^{*0}(1430)\pi^+$	$0.14 \pm 0.10 \pm 0.04 \pm 0.14$
$K_0^{*+}(1430)\pi^0$	$0.26 \pm 0.12 \pm 0.08 \pm 0.12$
$\rho^+(770)K^0$	$0.21 \pm 0.19 \pm 0.07 \pm 0.30$



The first evidence (3.4σ) of the direct CP violation in $B^+ \rightarrow K^{*+}\pi^0$ is obtained.
The first measurements of $Br(B^+ \rightarrow K^0\pi^+\pi^0)$ (inclusive) = $(45.9 \pm 2.6 \pm 3.0 \pm 8.6) \times 10^{-6}$
and $Br(B^+ \rightarrow K^{*+}(1430)\pi^0)$ = $(17.2 \pm 2.4 \pm 1.5 \pm 1.8) \times 10^{-6}$ are obtained as well.

- Kinematical parameters ($m_{KS\pi^+}$, $m_{KS\pi^0}$) are used to isolate several $K^0\pi^+$ resonances in the data sample.

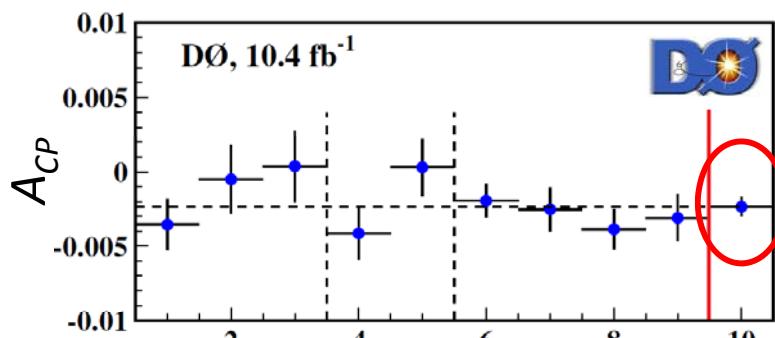
Dimuon Charge Asymmetry

- **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, PRD 89, 012002 (2014) (10.4 fb^{-1}).



Event category ID (all IP's are integrated)

All categories combined.

$A_{CP} = (-0.235 \pm 0.065 \pm 0.055)\%$,
3.6 σ deviation
from the SM prediction.
Hint for the NP?

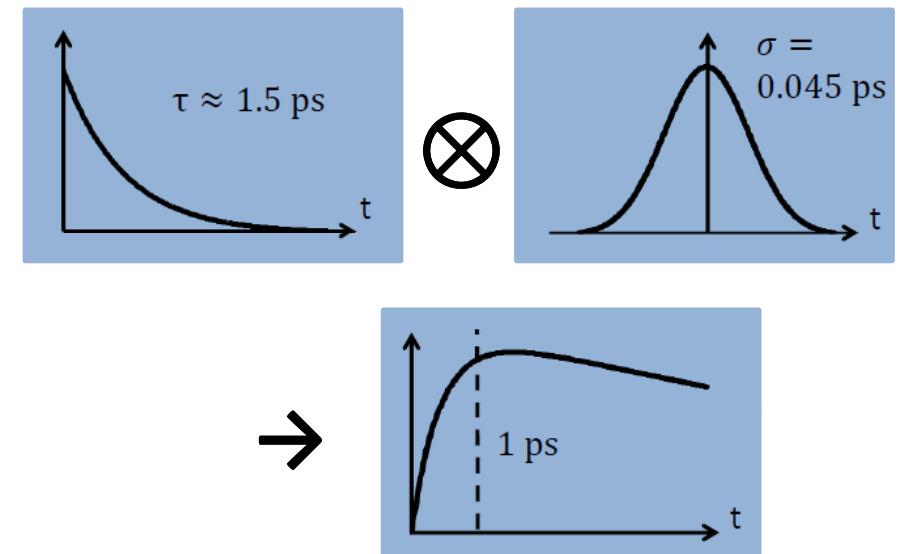
B Meson Lifetimes

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

Measurements by Belle, BaBar, CDF,
DØ, ATLAS, CMS, LHCb, et al.

- **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).

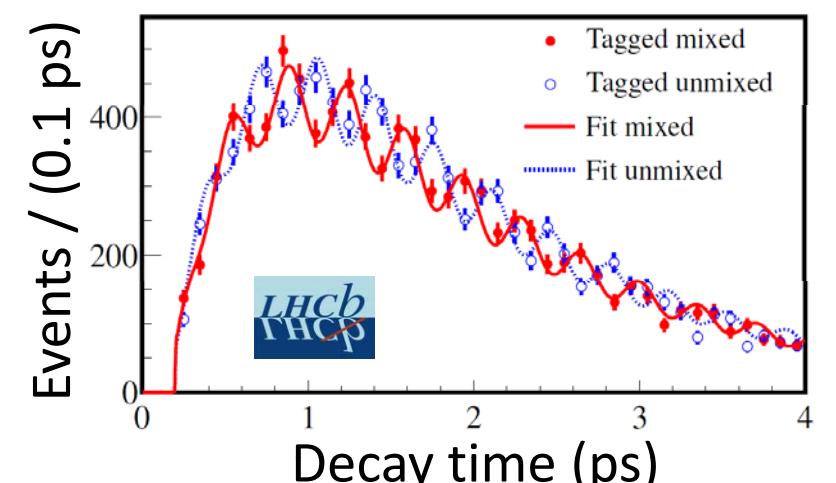


B_s - \bar{B}_s Mixing

- B_s - \bar{B}_s mixing Δm_s = another important input
 - The Δm_s is a key input to access to the CP -violating phase ϕ_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});
 CDF, PRL 97, 242003 (2006).



$\sigma(\text{decay-time}) @ \text{LHCb} \sim 45 \text{ fs.}$

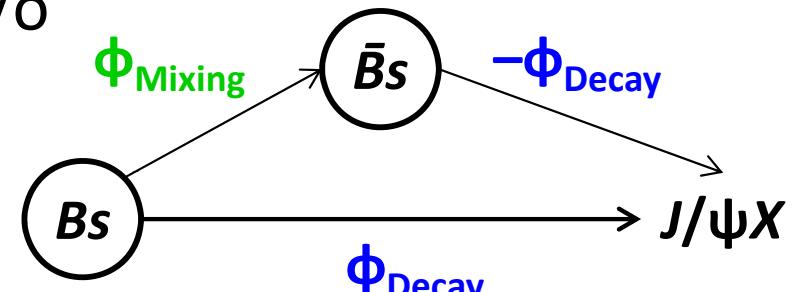
CP Violation in B_s System

- The *CP*-violating phase $\phi_s^{c\bar{c}s}$ in $B_s \rightarrow J/\psi X$

- Interference between w/ and w/o the mixing enables to access to the *CP*-violating phase.

- $\phi_s^{c\bar{c}s} = \phi_{\text{Mixing}} - 2\phi_{\text{Decay}}$

$$\phi_{\text{Decay}} \approx 0 \text{ (SM)} \rightarrow \phi_s^{c\bar{c}s} \approx \phi_{\text{Mixing}} \approx 0.04 \text{ (SM prediction).}$$

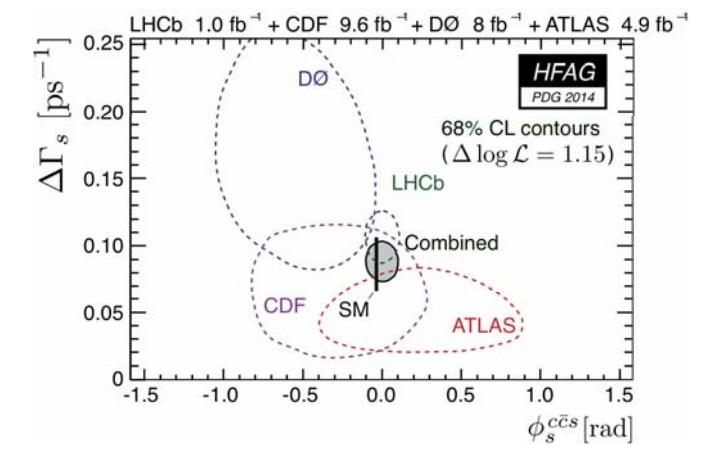
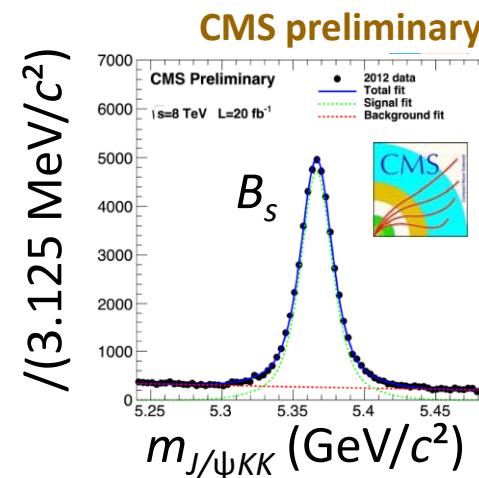
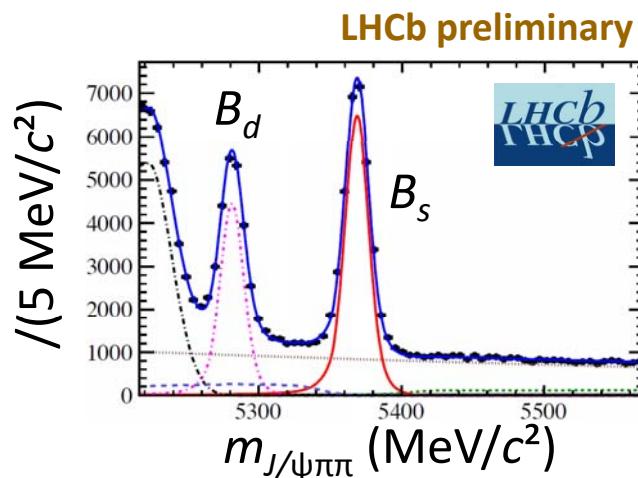


- Analysis method: similar to the ϕ_1 case

- Reconstruct $B_s \rightarrow J/\psi X$ candidate; tag the opposite B -meson flavor (B/\bar{B}); obtain decay length (typically ≈ 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

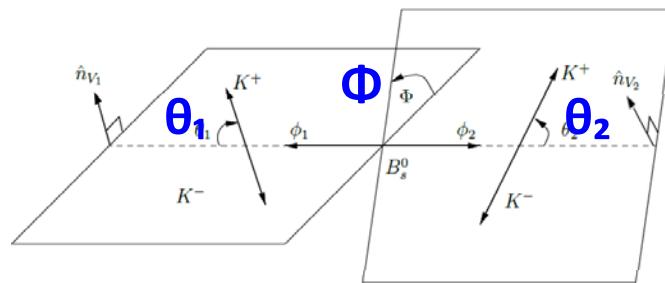
- $\Phi_s^{c\bar{c}s} = +0.00 \pm 0.07$ (HFAG winter-2014)
 - ATLAS (4.9 fb^{-1}): $\phi_s^{J/\psi\phi} = -0.12 \pm 0.25 \pm 0.05 \text{ rad}$
 - CMS (20 fb^{-1}): $\phi_s^{J/\psi\phi} = -0.03 \pm 0.11 \pm 0.03 \text{ rad}$ (*new*)
 - LHCb (3.0 fb^{-1}): $\phi_s^{J/\psi\pi\pi} = +70 \pm 68 \pm 8 \text{ mrad}$ (*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}): $\phi_s^{J/\psi\pi\pi}: [-\pi/2, -1.51] \cup [-0.06, 0.30] \cup [1.26, \pi/2]$
 - D \emptyset (8 fb^{-1}): $\phi_s^{J/\psi\phi} = -0.55^{+0.38}_{-0.36}$



CP Violation in B_s System

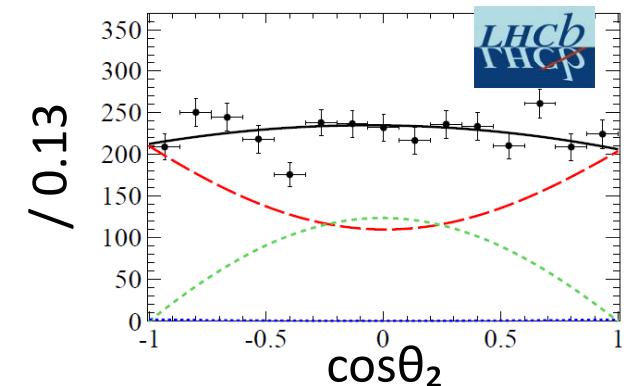
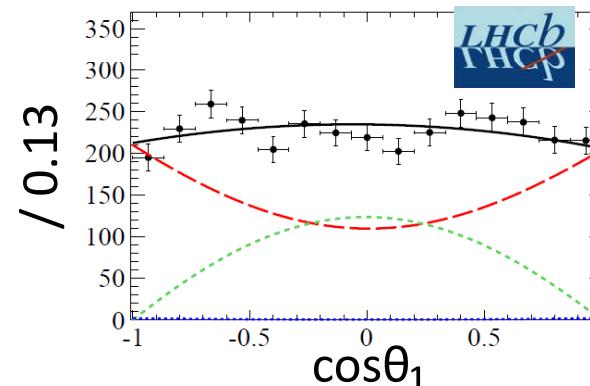
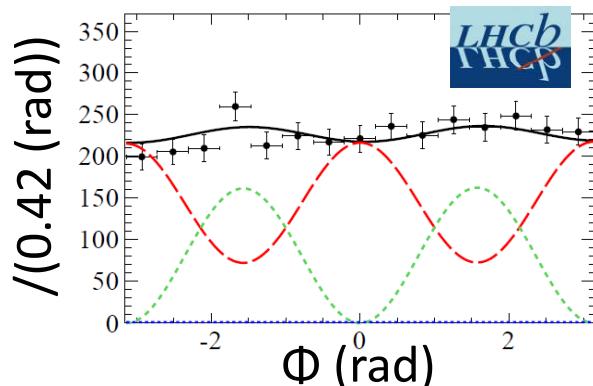
- $\phi_s \Phi\Phi = -0.17 \pm 0.12 \pm 0.04$ LHCb, arXiv:1407.2222 (2014) (3 fb^{-1}).

- The $B_s \rightarrow \phi\phi$ is a pure-penguin mode with $b \rightarrow s q \bar{q}$.
- The SM predicts $\phi_s \Phi\Phi = 0$ with low uncertainty.
- Angular analysis of the $B_s \rightarrow K^+ K^- K^+ K^-$:



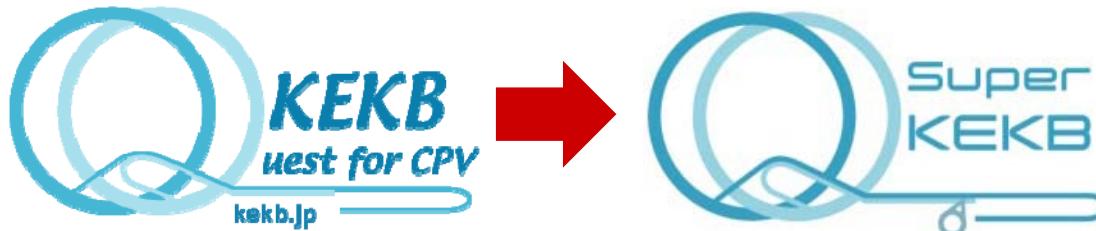
- x3 P -wave amplitudes:
 $A_0, A_{||}$ (CP -even), and A_{\perp} (CP -odd)
- x2 S -wave amplitudes:
 $A_S(\phi f_0$ CP -odd) and $A_{SS}(f_0 f_0$ CP -even)

- Observed distributions of θ_1, θ_2 , and Φ by the LHCb

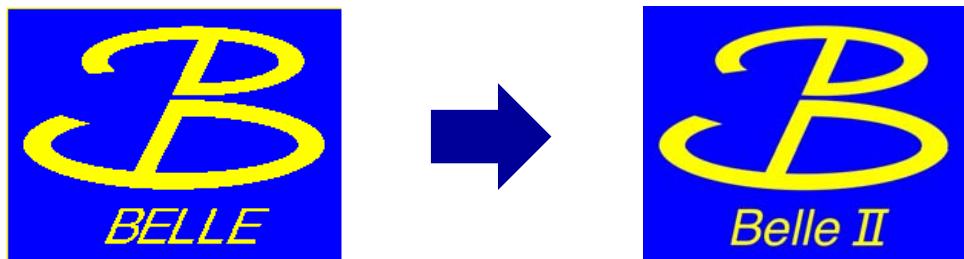


B Factory Upgrade: Belle II/SuperKEKB

- 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.



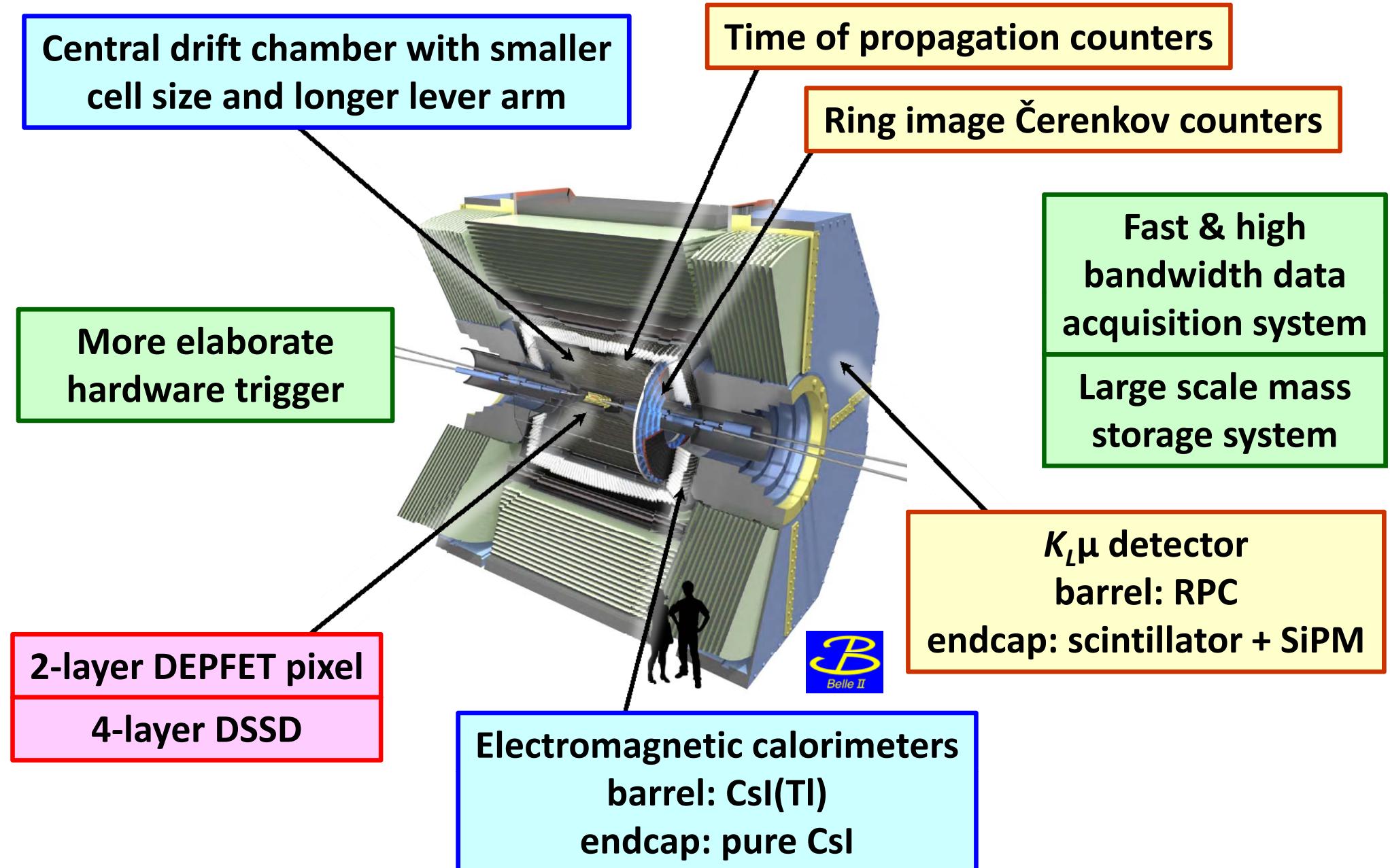
x40 luminosity,
 $L = 8.0 \times 10^{35} \text{cm}^{-2}\text{s}^{-1}$.



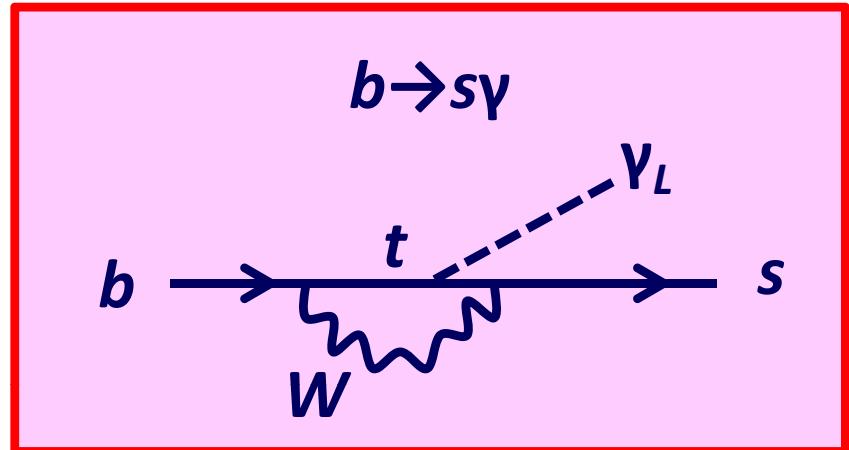
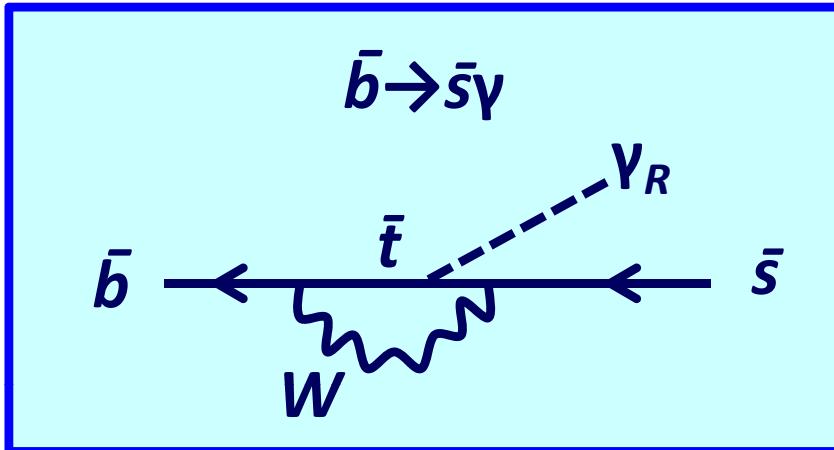
More granular resolution.
Faster signal output.
Robustness to higher BG.

The SuperKEKB commissioning will start in 2015.

Belle II Detector in a Nutshell



CP Violation in $B^0 \rightarrow K^0_S \pi^0 \gamma$ ($b \rightarrow s \gamma$)



$\bar{b} \rightarrow \bar{s} \gamma_R$
photon helicity is right-handed

$b \rightarrow s \gamma_L$
photon helicity is left-handed



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:

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

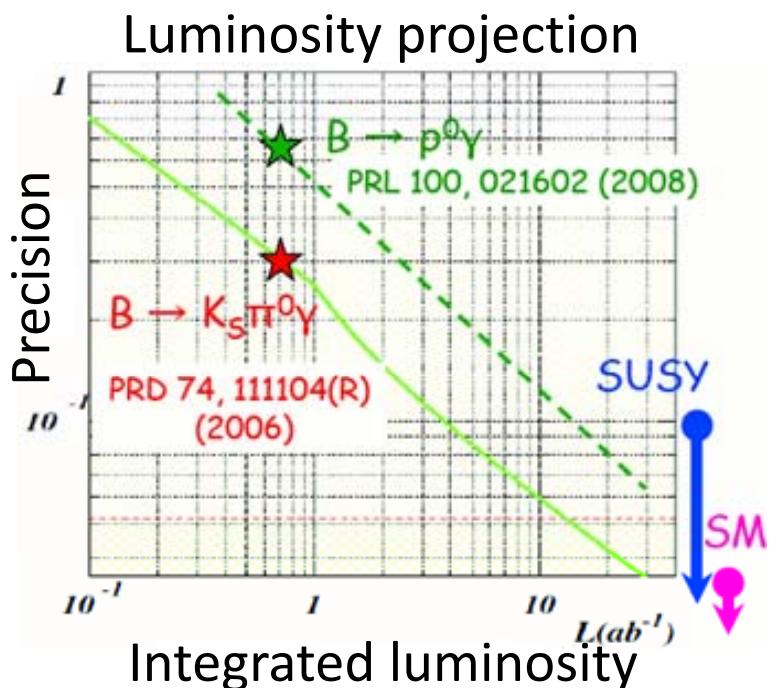
Analysis procedure is similar to that of $B^0 \rightarrow (c\bar{c})K^0$.

CP Violation in $B^0 \rightarrow K_s^0 \pi^0 \gamma$ ($b \rightarrow s \gamma$)

\downarrow
 $S_{b \rightarrow s \gamma}^{\text{SM}} \approx (\sin 2\phi_1) \times \left(-\frac{2m_s}{m_b} \right)$
 $S^{\text{average}} = -0.15 \pm 0.20$
 (HFAG winter-2009)
 Belle, PRD 74, 111104(R) (2006) (535M $B\bar{B}$);
 BaBar, PRD 78, 071102 (2008) (467M $B\bar{B}$).

\downarrow
 $S^{\text{NP}} \approx +0.67$
A NP (left-right symmetric model) may enhance CP violation in this decay.

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



Prospect

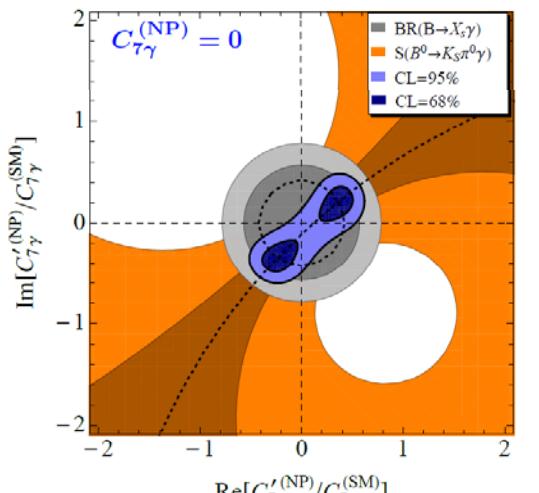
$$\delta(S_{b \rightarrow s \gamma}) \sim 0.09 @ 5 ab^{-1}$$

$$\delta(S_{b \rightarrow s \gamma}) \sim 0.03 @ 50 ab^{-1}$$

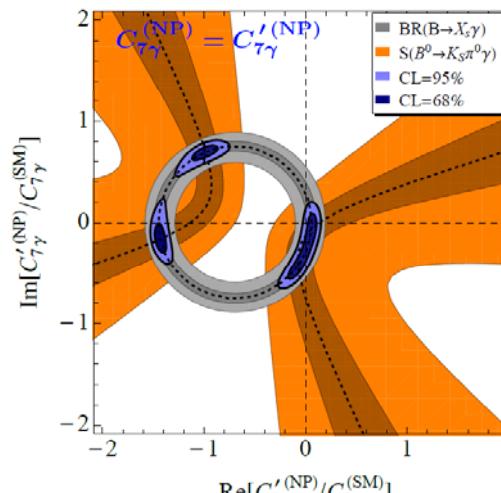
CP Violation in $B^0 \rightarrow K_s^0 \pi^0 \gamma$ ($b \rightarrow s \gamma$)

D. Becirevic *et al.*, arXiv:1206.1502 (2012).

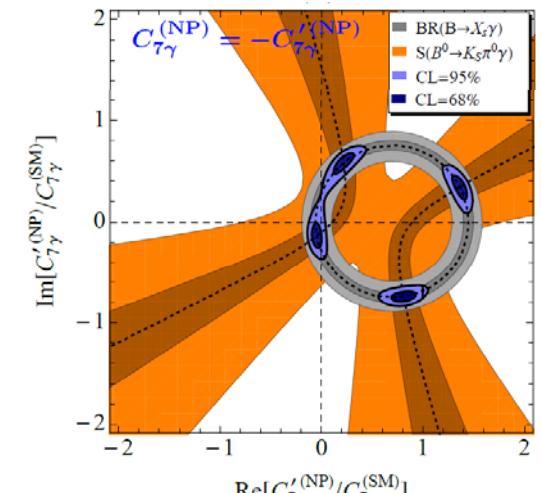
- **Detection of the NP effect in the C_7'**
 - The C_7 and C_7' of the Wilson coefficients correspond to left- and right-handed EM penguin operator, respectively
 $\rightarrow C_7' \approx 0$ in the SM $\rightarrow C_7' \gg 0$ indicates the NP.
 - $Br(B \rightarrow X_s \gamma)$, $S_{KS\pi^0\gamma}$,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



$C_7^{(NP)} = 0, C_7'^{(NP)} \in \text{complex}$



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

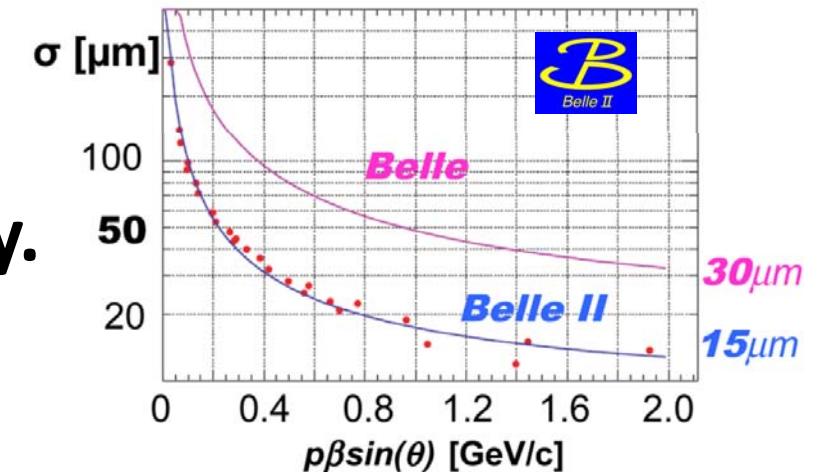


$C_7^{(NP)} = -C_7'^{(NP)} \in \text{complex}$

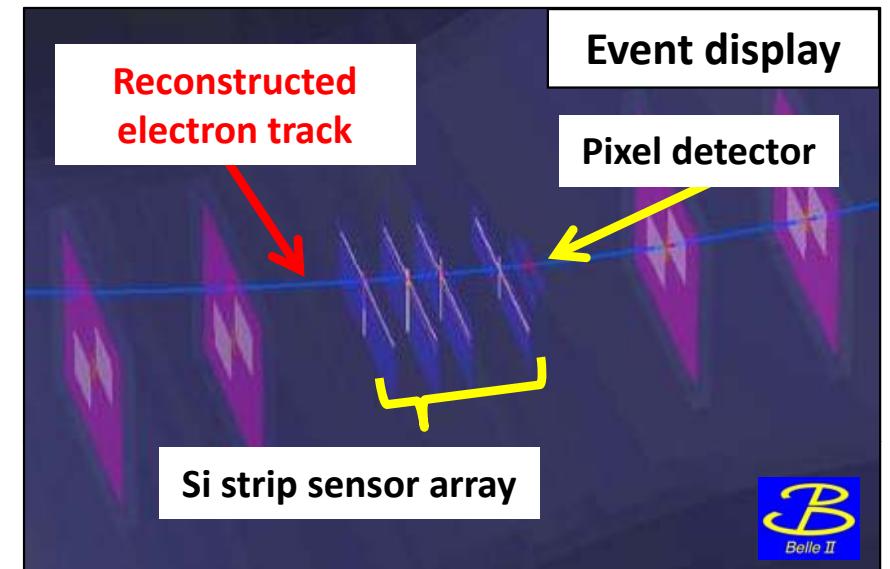
Belle II Vertex Detector

- 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.

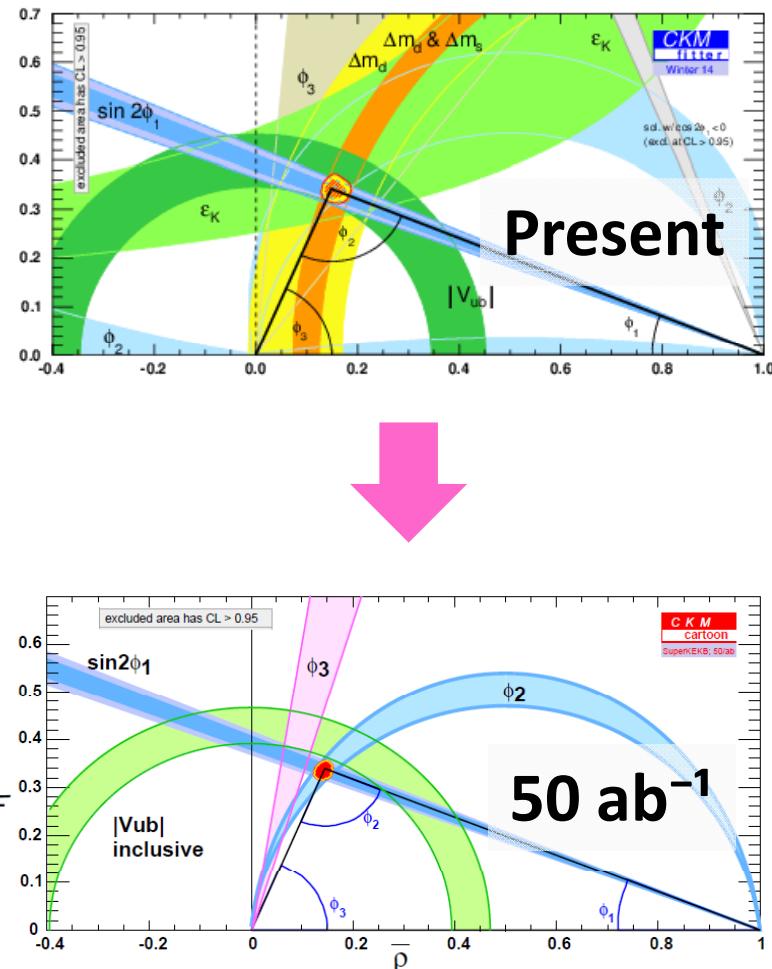


- System test at the DESY beam line in Jan. 2014
 - Good performance of the vertex detector is demonstrated together with its data acquisition system.



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 $b \rightarrow s q \bar{q}$, $K\pi$ 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 $b \rightarrow s q \bar{q}$ Transition

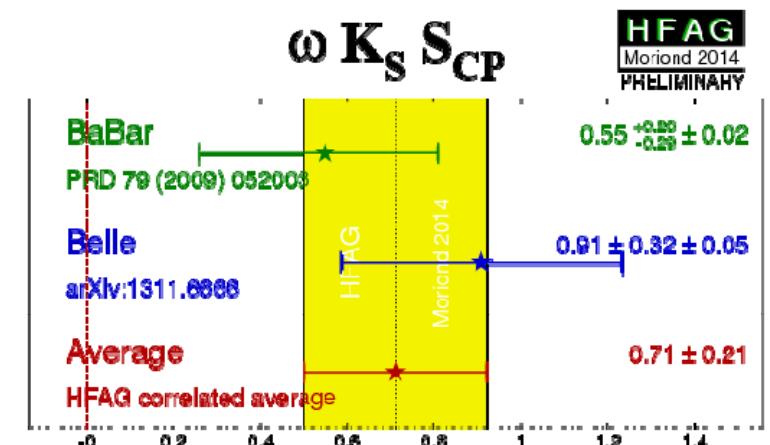
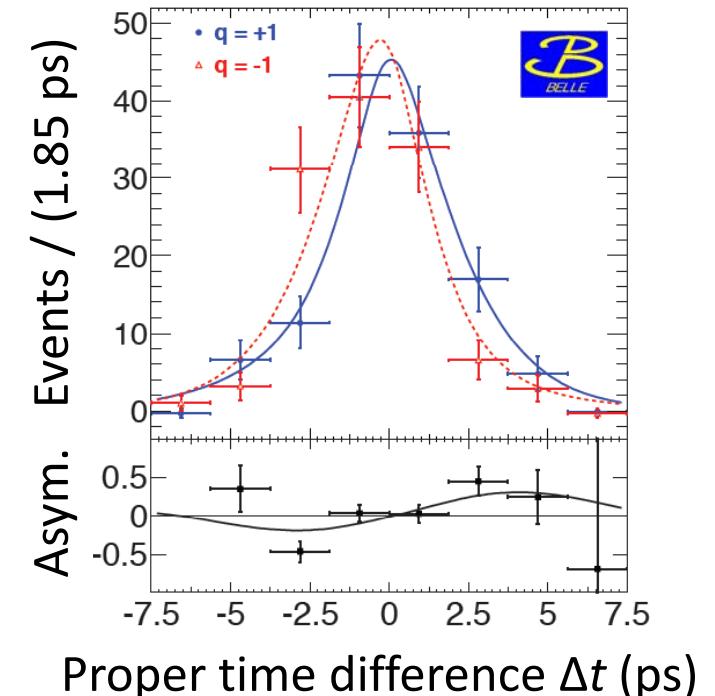
Belle, PRD 90, 012002 (2014) (772M $B\bar{B}$).

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

(HFAG winter-2014)

		$-\xi_f S_f$	$+0.91 \pm 0.32 \pm 0.05$
Belle (772M $B\bar{B}$)	A_f	$-0.36 \pm 0.19 \pm 0.15$	
	$-\xi_f S_f$	$+0.55^{+0.26}_{-0.29} \pm 0.02$	
BaBar (467M $B\bar{B}$)	A_f	$-0.52^{+0.22}_{-0.20} \pm 0.03$	
	$-\xi_f S_f$	0.71 ± 0.21	
Average		A_f	$-0.04 \pm 0.19 \pm 0.15$

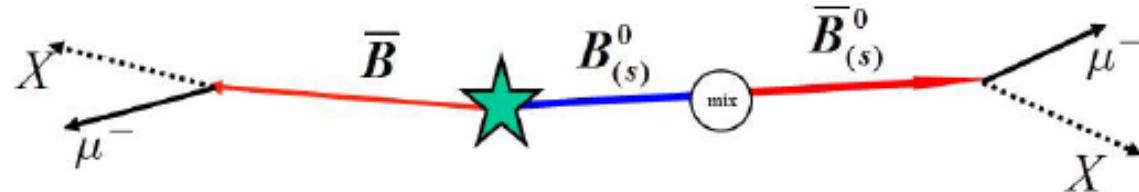
- The first evidence of the non-zero $-\xi_f S_f$ for the $B^0 \rightarrow \omega K^0$ is given.



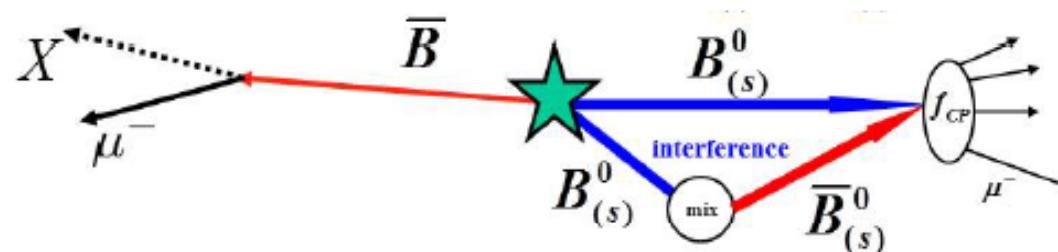
Dimuon Charge Asymmetry

- **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:

$$\Gamma(B_{(s)}^0 \rightarrow \bar{B}_{(s)}^0 \rightarrow \mu^- X) \neq \Gamma(\bar{B}_{(s)}^0 \rightarrow B_{(s)}^0 \rightarrow \mu^+ X)$$



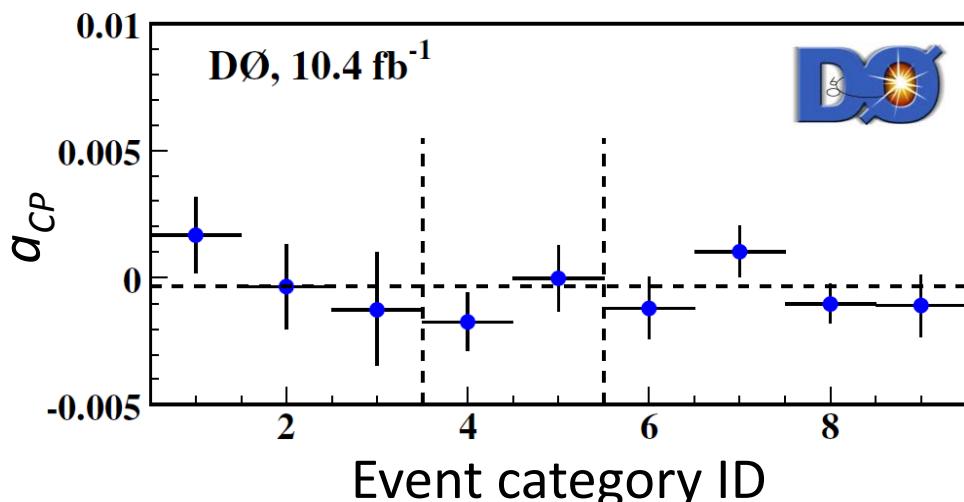
- CP violation in interference between w/ and w/o the mixing: $\Gamma(B_{(s)}^0 (\rightarrow \bar{B}_{(s)}^0) \rightarrow f_{CP}) \neq \Gamma(\bar{B}_{(s)}^0 (\rightarrow B_{(s)}^0) \rightarrow f_{CP})$



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.

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



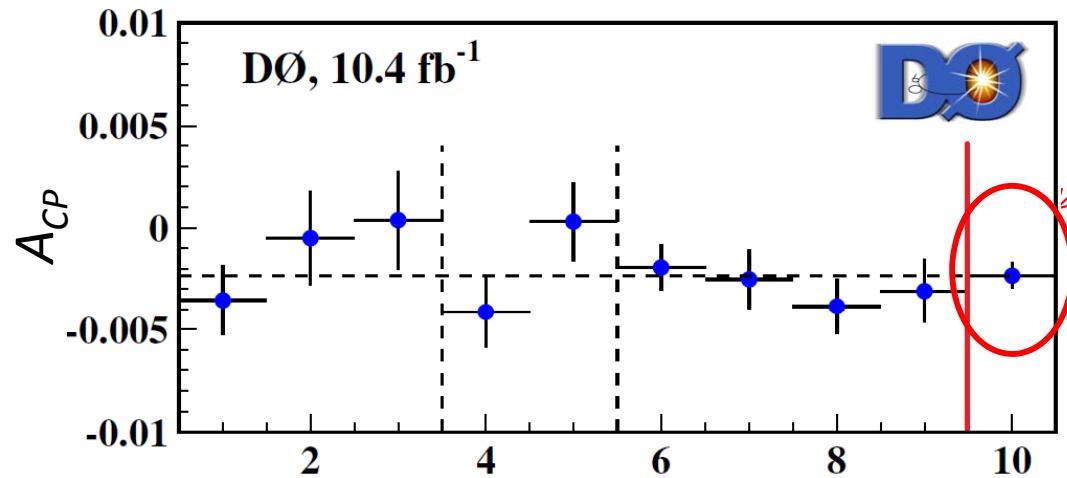
$a_{CP} = (-0.032 \pm 0.042 \pm 0.061)\%$,
consistent with zero.

Events are categorized by p_T , absolute value of the pseudorapidity, and impact parameter (integrated in the left figure) of the muon.

Dimuon Charge Asymmetry

- DØ measurement (dimuon charge asymmetry)

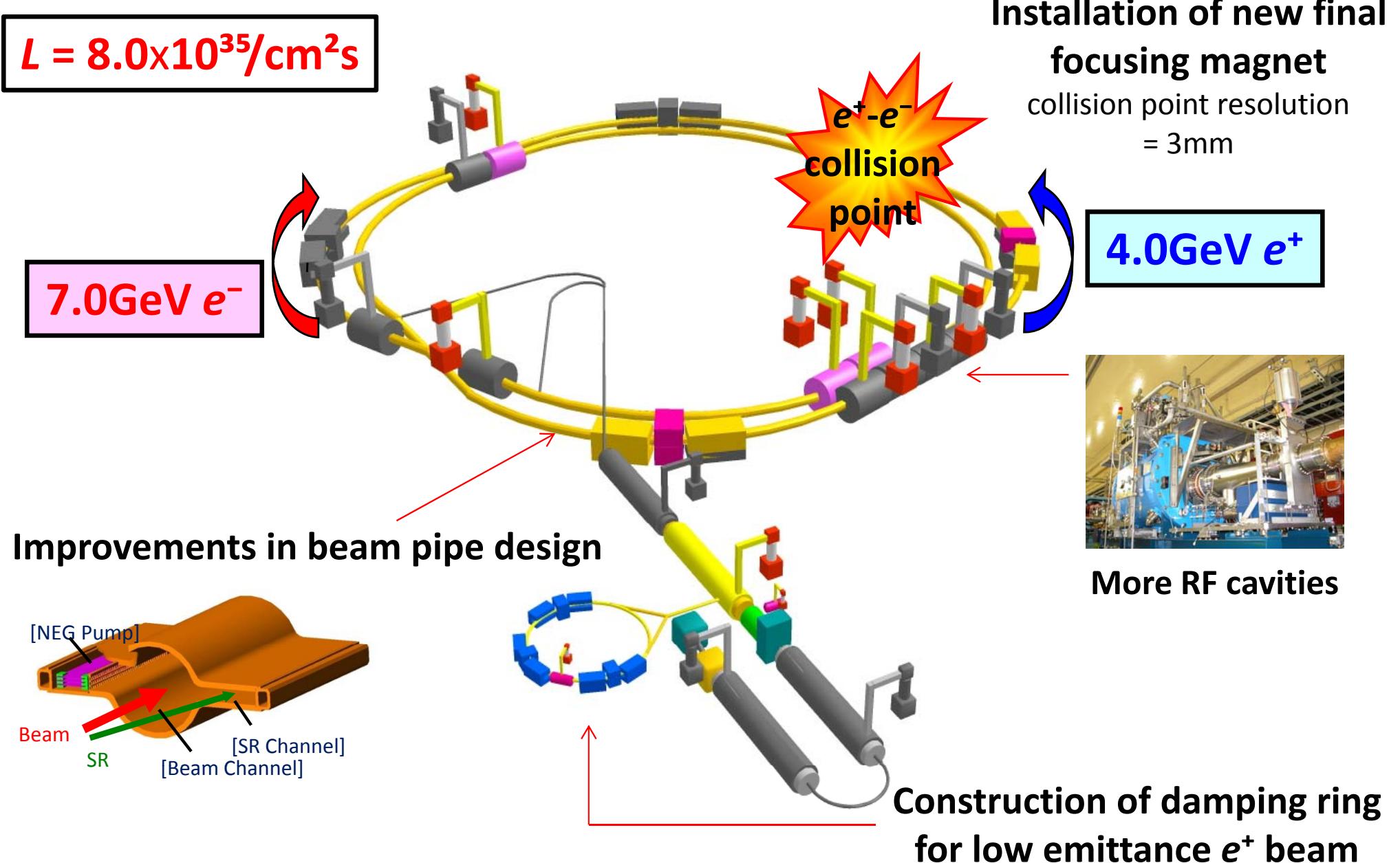
DØ, PRD 89, 012002 (2014) (10.4 fb^{-1}).



All categories combined.
 $A_{CP} = (-0.235 \pm 0.065 \pm 0.055)\%$,
3.6 σ deviation
from the SM prediction.

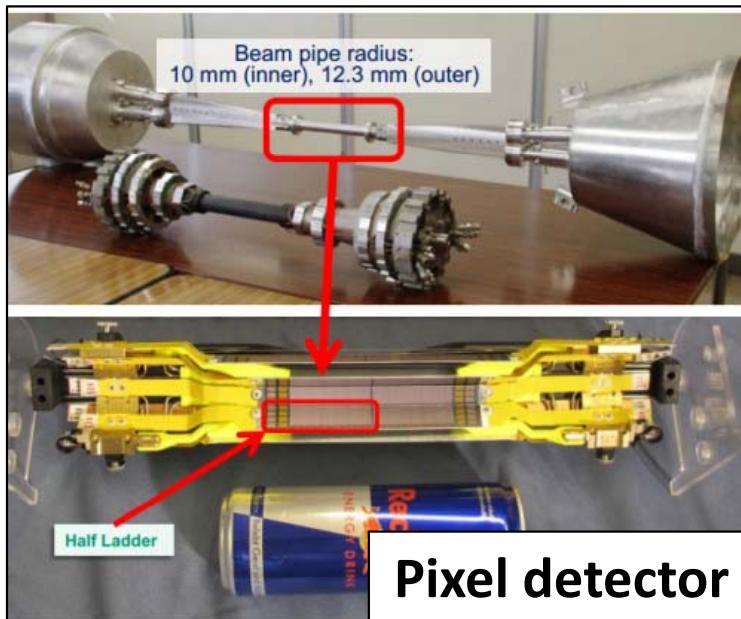
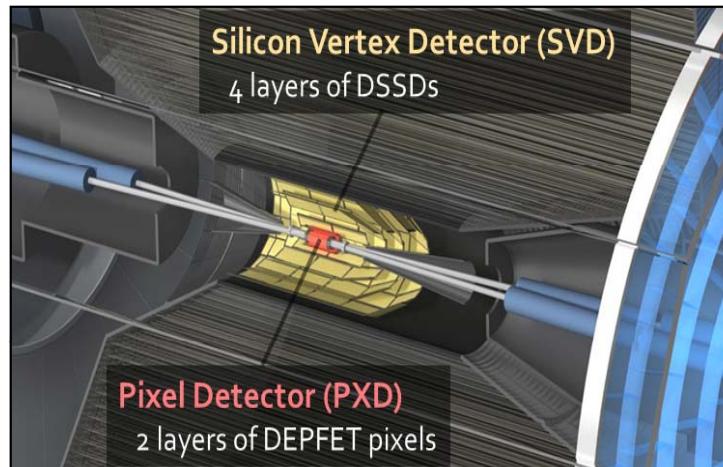
Hint for the NP?

SuperKEKB Accelerator in a Nutshell



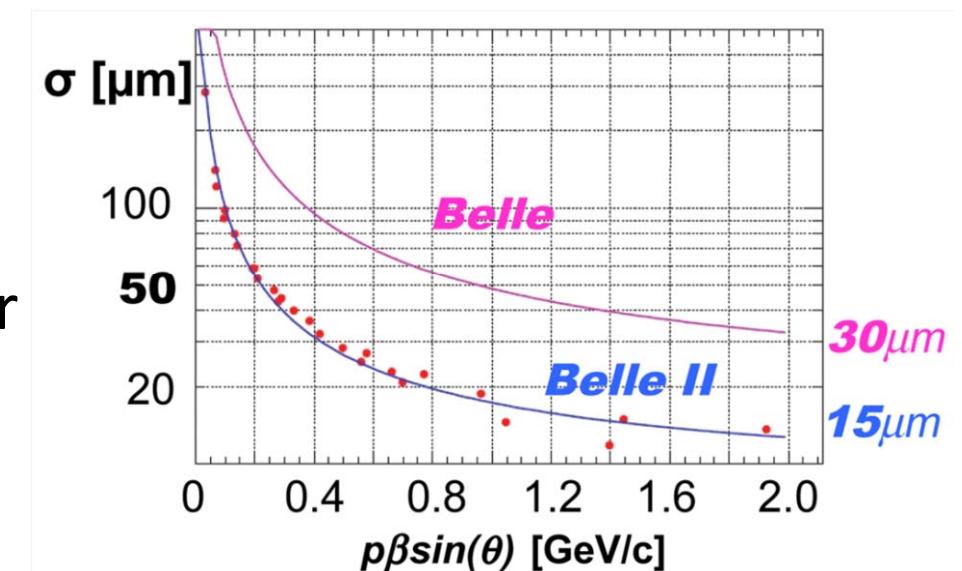
Belle II Vertex Detector

The very central part of the Belle II detector



Belle II Vertex Detector

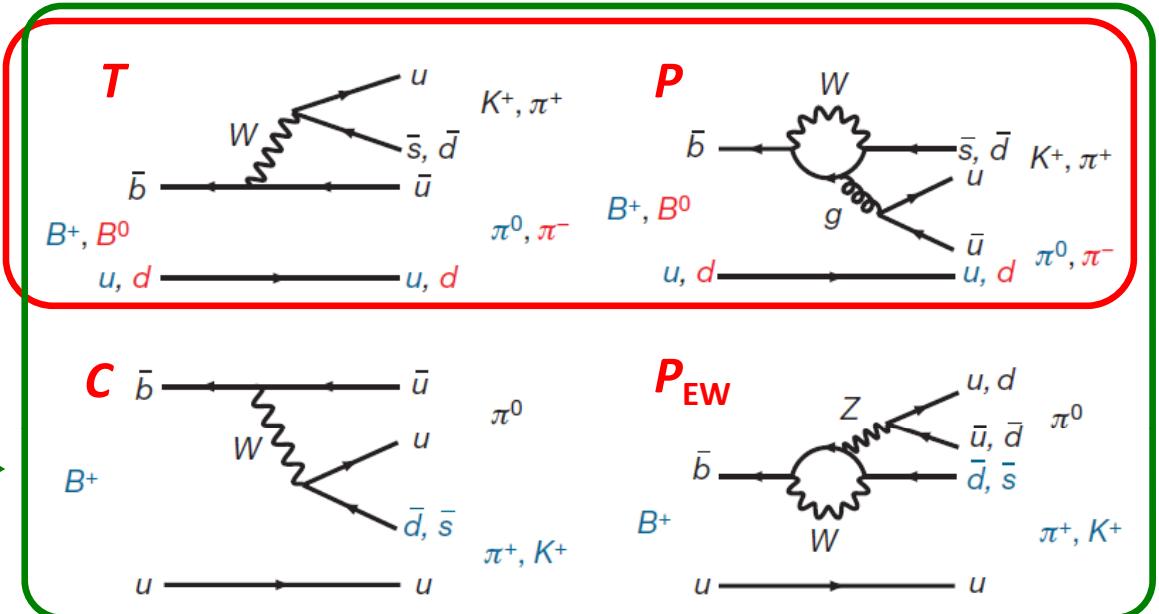
- A precision vertex detector is needed to measure the time-dependent CP -violating parameter $S_{KS\pi^0\gamma}$.
 - History
 - Belle (the 1st period): 3 layers of Si strip sensor array.
 - Belle (the 2nd period): 4 layers of Si strip sensor array.
 - **Belle II: 2 layers of pixel detector + 4 layers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



CP Violation Anomaly in B^0/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

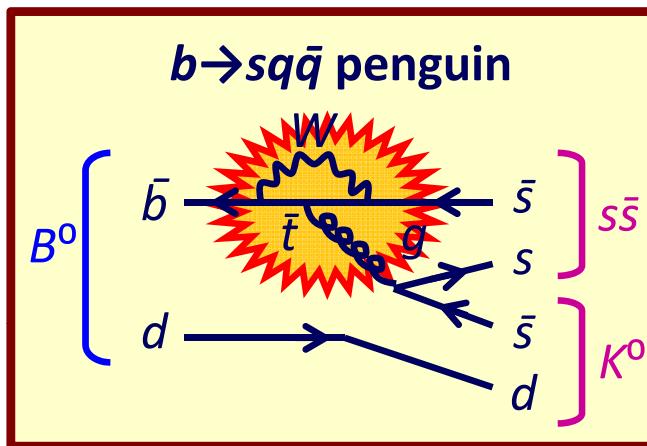
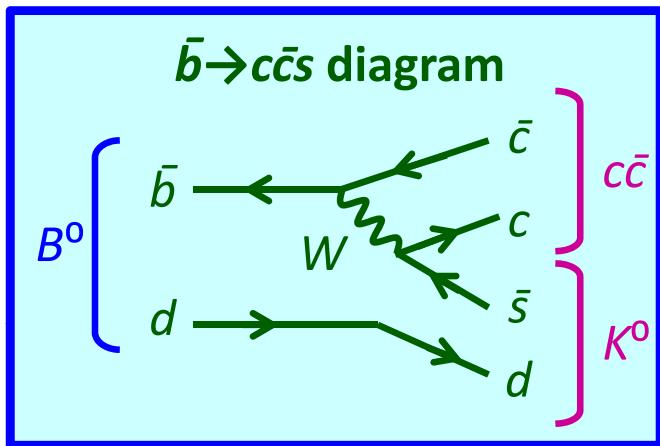
$$\mathcal{A}_{CP}(K^+\pi^-) + \mathcal{A}_{CP}(K^0\pi^+) \frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)} \frac{\tau_0}{\tau_+} = \mathcal{A}_{CP}(K^+\pi^0) \frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)} \frac{\tau_0}{\tau_+} + \mathcal{A}_{CP}(K^0\pi^0) \frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

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.

$0.14 \pm 0.13 \pm 0.06$
@ 600 fb^{-1} (Belle)

Prospect The sum rule can be checked with 10 ab^{-1} data

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



(HFAG winter-2014)

$$\sin 2\phi_1^{sq\bar{q}}_{W.A} = +0.655 \pm 0.032$$

$$\sin 2\phi_1^{c\bar{c}s}_{W.A} = +0.682 \pm 0.019$$

0.7 σ deviation

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

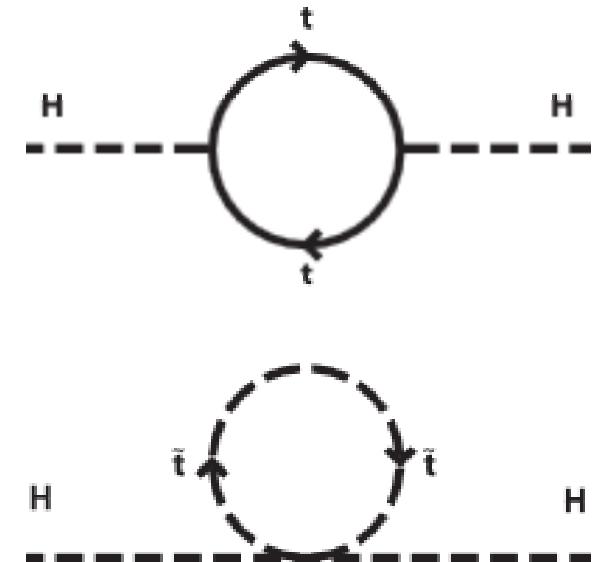
The Belle II may find a NP effect in the $b \rightarrow sq\bar{q}$ with **50ab⁻¹** data assuming the present discrepancy holds.

Prospect $\delta(S_{b \rightarrow s}) \sim 0.012 @ 50ab^{-1}$

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 Λ is a scale of new physics.
- If no new physics until the Planck scale $O(10^{18} \text{ GeV}/c^2)$, Λ 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.



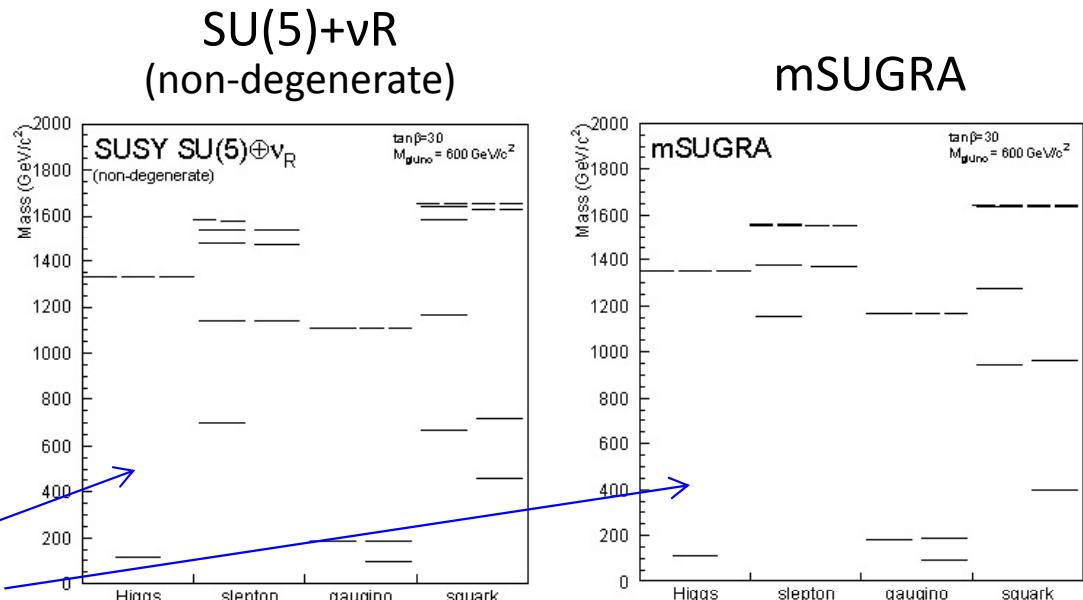
Complementarity (Belle II & LHCb)

Energy frontier

↑
Direct detection
of SUSY particles

Mass spectra are insufficient
to figure out the SUSY model.

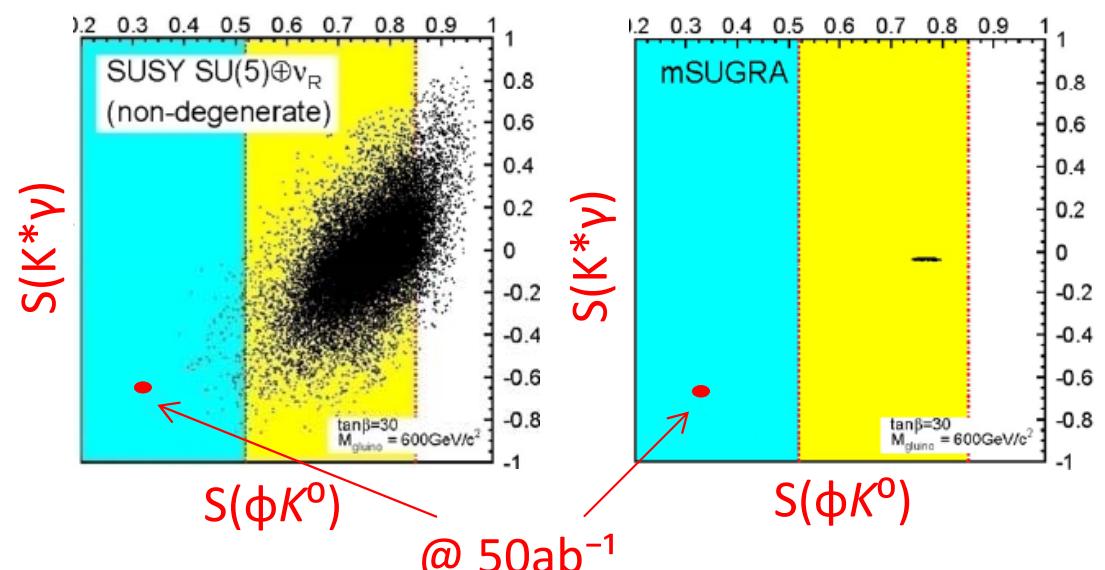
Similar mass spectra show up
across different SUSY models.



Luminosity frontier

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

Various analyses on B , τ ,
charm, ... decays enable to
reveal the SUSY model.



Complementarity (Belle II & LHCb)

Observable	SM prediction	Theory error	Present result	Future error	Future Facility
$ V_{us} [K \rightarrow \pi \ell \nu]$	input	$0.5\% \rightarrow 0.1\%$ _{Latt}	0.2246 ± 0.0012	0.1%	K factory
$ V_{cb} [B \rightarrow X_c \ell \nu]$	input	1%	$(41.54 \pm 0.73) \times 10^{-3}$	1%	Super- B
$ V_{ub} [B \rightarrow \pi \ell \nu]$	input	$10\% \rightarrow 5\%$ _{Latt}	$(3.38 \pm 0.36) \times 10^{-3}$	4%	Super- B
$\gamma [B \rightarrow DK]$	input	$< 1^\circ$	$(70^{+27}_{-30})^\circ$	3°	LHCb
$S_{B_d \rightarrow \psi K}$	$\sin(2\beta)$	$\lesssim 0.01$	0.671 ± 0.023	0.01	LHCb
$S_{B_s \rightarrow \psi \phi}$	0.036	$\lesssim 0.01$	$0.81^{+0.12}_{-0.32}$	0.01	LHCb
$S_{B_d \rightarrow \phi K}$	$\sin(2\beta)$	$\lesssim 0.05$	0.44 ± 0.18	0.1	LHCb
$S_{B_s \rightarrow \phi \phi}$	0.036	$\lesssim 0.05$	—	0.05	LHCb
$S_{B_d \rightarrow K^* \gamma}$	$\text{few} \times 0.01$	0.01	-0.16 ± 0.22	0.03	Super- B
$S_{B_s \rightarrow \phi \gamma}$	$\text{few} \times 0.01$	0.01	—	0.05	LHCb
A_{SL}^d	-5×10^{-4}	10^{-4}	$-(5.8 \pm 3.4) \times 10^{-3}$	10^{-3}	LHCb
A_{SL}^s	2×10^{-5}	$< 10^{-5}$	$(1.6 \pm 8.5) \times 10^{-3}$	10^{-3}	LHCb
$A_{CP}(b \rightarrow s \gamma)$	< 0.01	< 0.01	-0.012 ± 0.028	0.005	Super- B
$\mathcal{B}(B \rightarrow \tau \nu)$	1×10^{-4}	$20\% \rightarrow 5\%$ _{Latt}	$(1.73 \pm 0.35) \times 10^{-4}$	5%	Super- B
$\mathcal{B}(B \rightarrow \mu \nu)$	4×10^{-7}	$20\% \rightarrow 5\%$ _{Latt}	$< 1.3 \times 10^{-6}$	6%	Super- B
$\mathcal{B}(B_s \rightarrow \mu^+ \mu^-)$	3×10^{-9}	$20\% \rightarrow 5\%$ _{Latt}	$< 5 \times 10^{-8}$	10%	LHCb
$\mathcal{B}(B_d \rightarrow \mu^+ \mu^-)$	1×10^{-10}	$20\% \rightarrow 5\%$ _{Latt}	$< 1.5 \times 10^{-8}$	[?]	LHCb
$A_{\text{FB}}(B \rightarrow K^* \mu^+ \mu^-)_{q_0^2}$	0	0.05	(0.2 ± 0.2)	0.05	LHCb
$B \rightarrow K \nu \bar{\nu}$	4×10^{-6}	$20\% \rightarrow 10\%$ _{Latt}	$< 1.4 \times 10^{-5}$	20%	Super- B
$ q/p _{D-\text{mixing}}$	1	$< 10^{-3}$	$(0.86^{+0.18}_{-0.15})$	0.03	Super- B
ϕ_D	0	$< 10^{-3}$	$(9.6^{+8.3}_{-9.5})^\circ$	2°	Super- B
$\mathcal{B}(K^+ \rightarrow \pi^+ \nu \bar{\nu})$	8.5×10^{-11}	8%	$(1.73^{+1.15}_{-1.05}) \times 10^{-10}$	10%	K factory
$\mathcal{B}(K_L \rightarrow \pi^0 \nu \bar{\nu})$	2.6×10^{-11}	10%	$< 2.6 \times 10^{-8}$	[?]	K factory
$R^{(e/\mu)}(K \rightarrow \pi \ell \nu)$	2.477×10^{-5}	0.04%	$(2.498 \pm 0.014) \times 10^{-5}$	0.1%	K factory
$\mathcal{B}(t \rightarrow c Z, \gamma)$	$\mathcal{O}(10^{-13})$	$\mathcal{O}(10^{-13})$	$< 0.6 \times 10^{-2}$	$\mathcal{O}(10^{-5})$	LHC (100 fb $^{-1}$)

Belle II and LHCb

	Belle	Belle II	Belle II	LHCb
	$\sim 0.5\text{ab}^{-1}$	5ab^{-1}	50ab^{-1}	$10\text{fb}^{-1} [5\text{yrs}]$
$\Delta S(\phi K_S)$	0.22	0.073	0.029	0.14
$\Delta S(\eta' K_S)$	0.11	0.038	0.020	–
ϕ_s from $S(J/\psi\phi)$	–	–	–	0.01
$S(K^*\gamma)$	0.36	0.12	0.03	–
$S(\rho\gamma)$	0.68	0.22	0.08	–
$\Delta Br/Br(B \rightarrow \tau\nu)$	3.5σ	10%	3%	–
$Bs \rightarrow \mu\mu$?	?	?	$5\sigma @ 6 \text{ fb}^{-1}$
$\tau \rightarrow \mu\mu [\times 10^{-9}]$	<45	<30	<8	–
$\tau \rightarrow \mu\mu\mu [\times 10^{-9}]$	<209	<10	<1	–
ϕ_2	11°	2°	1°	4.5°
ϕ_3	16°	6°	2°	2.4°

- **Belle II and LHCb complementarily elucidate a NP.**
 - The Belle II can provide important physics relevant to the modes with γ , π^0 , ν , K_S^0 , etc ... ($B \rightarrow \tau\nu$, $b \rightarrow sq\bar{q}$, τ LFV...).