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

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FLASY 2018

Outline

1. Introduction
   - Unitary triangle
   - SuperKEKB and Belle II
2. Time Dependent $\not{CP}$ Violation Measurements
3. ϕ_1/β measurement
   - $b \to c\bar{c}s$ transition
   - $b \to q\bar{q}s$ transition
4. ϕ_2/α measurement
   - $\mathrm{B} \to \pi\pi$
   - $\mathrm{B} \to \rho\rho$
5. New Physics with TDCPV
   - $\mathrm{B}^0 \to \mathrm{K}^0_S\pi^0\gamma$
6. Conclusion and outlook

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Introduction

CPV

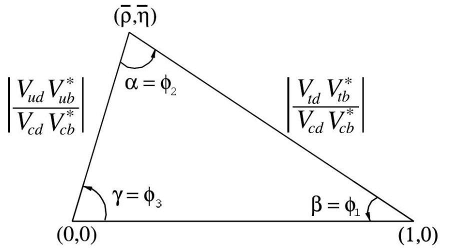
- Why CP-Violation?
  - Matter-Antimatter asymmetry in the universe.
  - Sakharov's 2^{nd} condition requires and CPV
  - current known CPV in SM way smaller than needed.
- B^0-system exhibits the largest CPV in the SM
- CPV in SM is due to weak interaction and it is described by V_{CKM} matrix ($\lambda = \cos\theta_C = 0.22$)

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

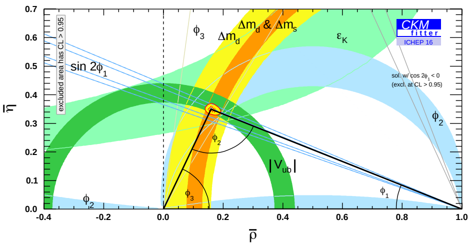
- Unitarity requires: $\Sigma_k V^*_{ki} V_{kj}$ so $V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0$
  - $\mathcal{O}(\lambda^3) + \mathcal{O}(\lambda^3) + \mathcal{O}(\lambda^3)$
- **main goal of Belle II is to precisely measure the CKM unitary triangle, and look for Beyond-SM physics using precision 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 $b \to c\bar{c}s$ and $b \to q\bar{q}s$
  - $\phi_2 = \alpha$: accessible via B^0 oscillation analysis $b \to u\bar{u}d$
  - $\phi_3 = \gamma$: relative phase of tree level bc and bu coupling;
- $\phi_{1,2}$ can be accessed via Time-Dependent $\not{CP}$ Violation analysis of asymmetry in B^0 meson decay rate into CP eigenstate (TDCPV)

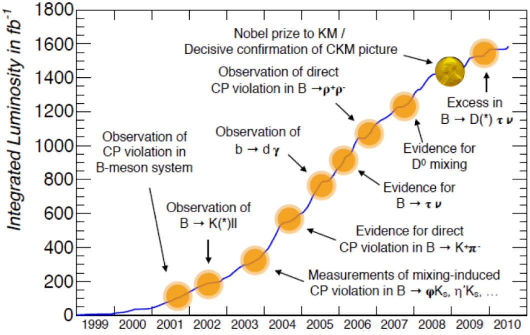


Current world average



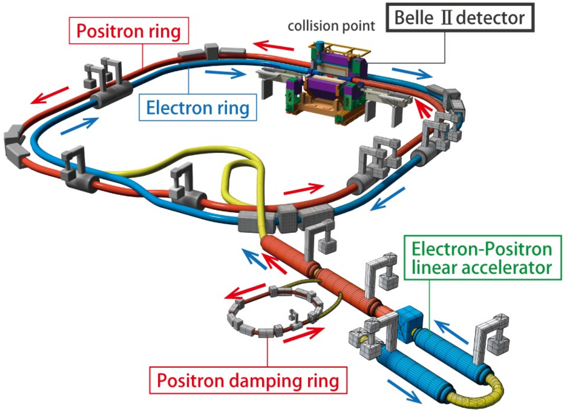
B-factories (BaBar @ SLAC and Belle @ KEKB): a 10 year long success:

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

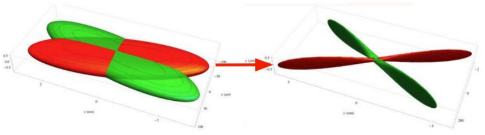


- Discovery of CPV in B-system, indirect and direct;
- confirmation of CKM description of flavour phys;
- precision measurement of CKM elements;
- obs of several new hadronic states
- strong evidence of D meson mixing

SuperKEKB



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



Nano Beam scheme:

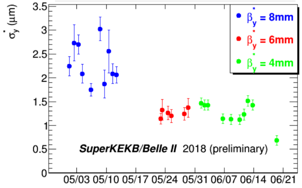
$\beta_y \sim$ x20 smaller at IP

Proposed by P.Raimondi for SuperB

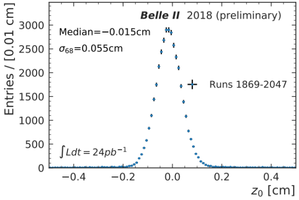
SuperKEKB

Nano Beam is working!

Vertical beam size



Measured z_0 resolution [BELLE2-NOTE-PL-2018-008]



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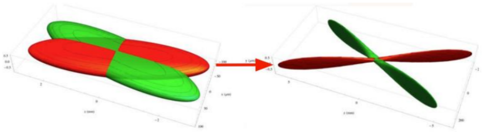

KEKB SuperKEKB

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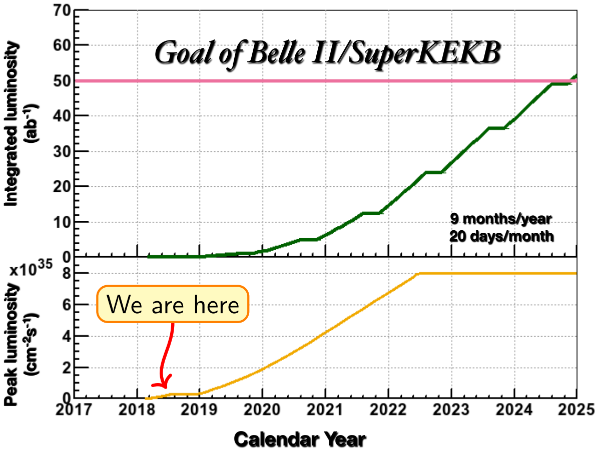
SuperKEKB



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

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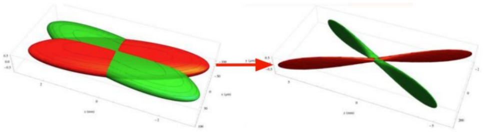

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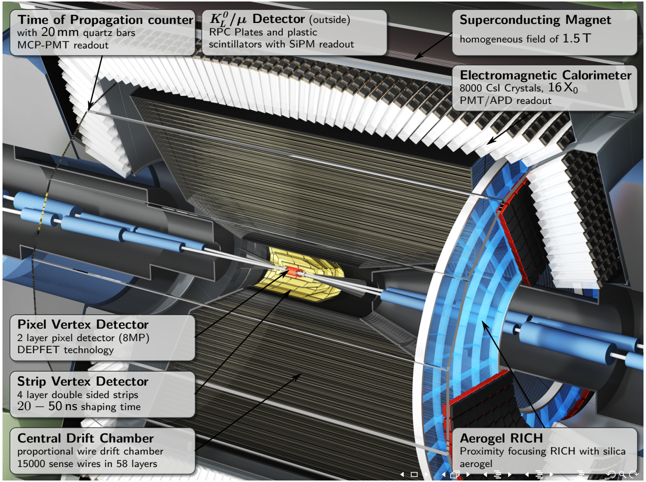
Proposed by P.Raimondi for SuperB

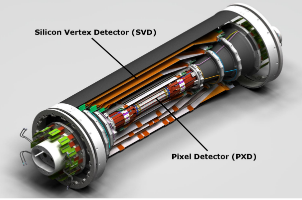
Belle II detector



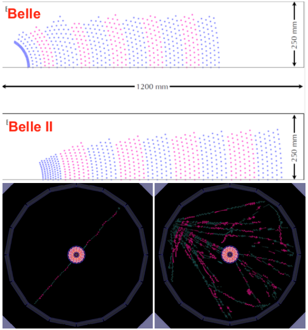
- **Challenges:**
  - Much higher background wrt to KEKB
  - Reduced CM boost wrt to Belle
- **Improvement** [Belle II TDR, arXiv:1011.0352]
  - New, extended vertex detector
    - 2 pixel layers: DEPFET technology
    - 4 layers of double sided Si microstrip sensors
  - Smaller cell size and longer 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, μ) electronics

Belle II: an improved detector

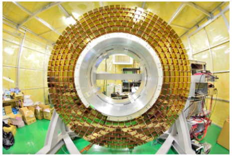
SVD and PXD



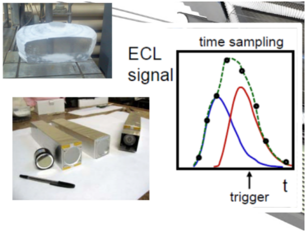
CDC



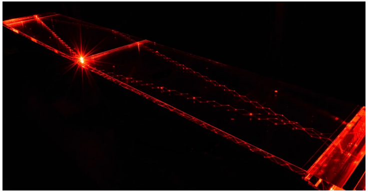
ARICH

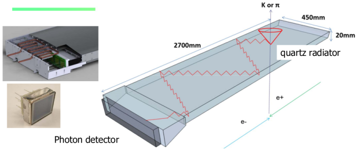


ECL

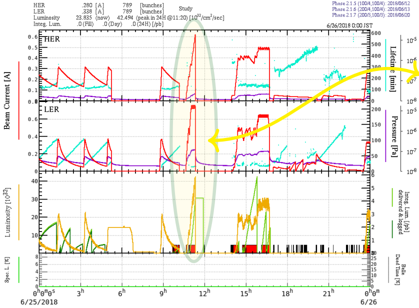


TOP

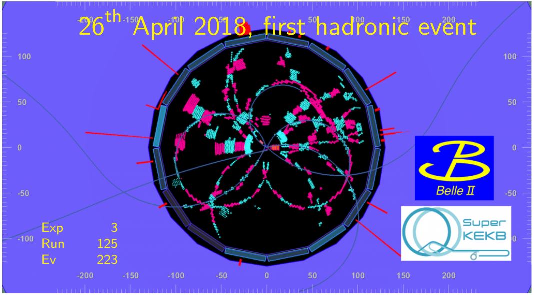


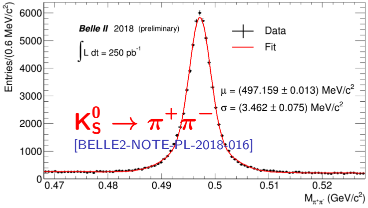


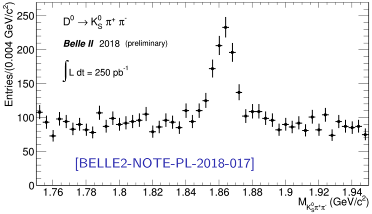
Propaganda plot: It's alive!

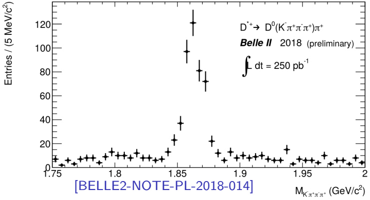


Record Lumi:
$4.2 \cdot 10^{33} \frac{1}{s \cdot cm^2}$



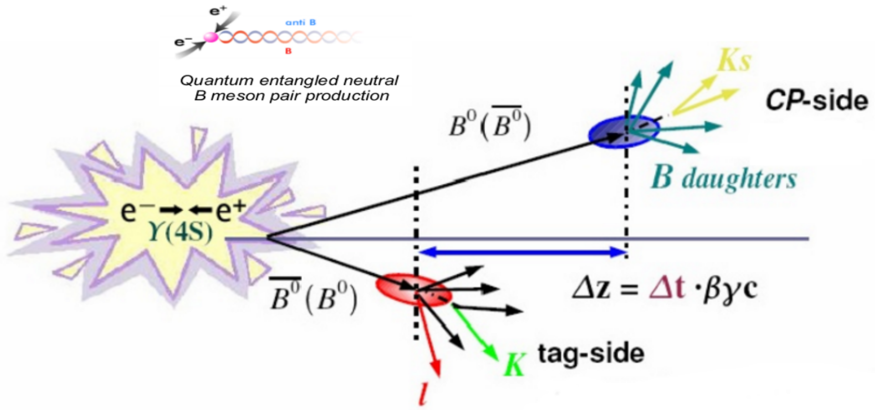






Outline

Time Dependent $\not{CP}$ Violation Measurements

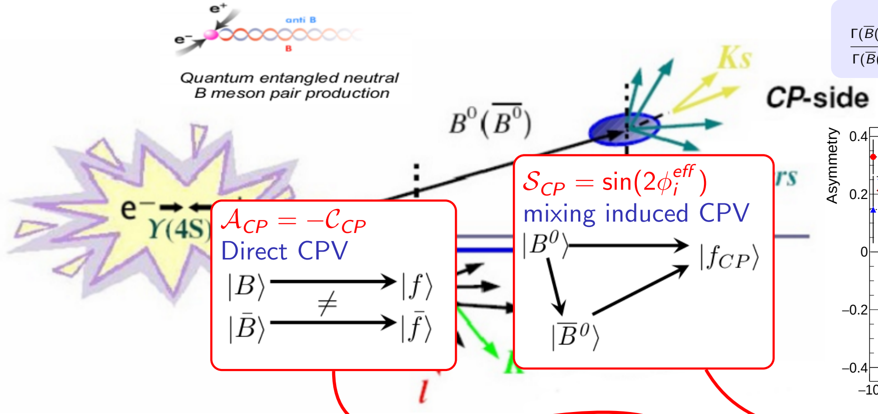


Time Dep. $\not{CP}$: a powerful tool to both perform

- precise measurement of the UT angles
- look for new physics BSM if decay via loop (eg charmless)
- possible with tree/penguin-dominated transitions:
  - $b \to c\bar{c}s$ ($B^0 \to J/\psi K^0$)
  - $b \to q\bar{q}s$ ($B^0 \to \eta' K^0$, $\phi K^0, \ldots$)

Time Dependent $\not{C}\not{P}$ Violation Measurements

$$Asym_{CP}(\Delta t) = \frac{\Gamma(\overline{B}(\Delta t) \to f_{CP}; \Delta t) - \Gamma(B(\Delta t) \to f_{CP}; \Delta t)}{\Gamma(\overline{B}(\Delta t) \to f_{CP}; \Delta t) + \Gamma(B(\Delta t) \to f_{CP}; \Delta t)}$$



$\mathcal{A}_{CP} = -\mathcal{C}_{CP}$

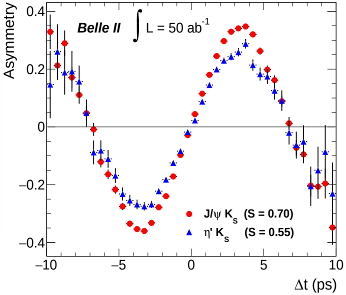
Direct CPV

$$|B\rangle \longrightarrow |f\rangle \quad \neq \quad |\bar{B}\rangle \longrightarrow |\bar{f}\rangle$$

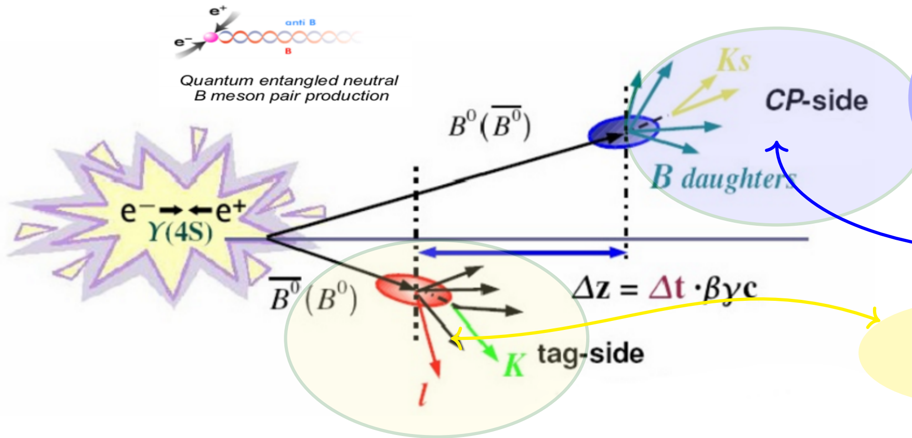
$\mathcal{S}_{CP} = \sin(2\phi_i^{eff})$

mixing induced CPV

$$|B^0\rangle \longrightarrow |f_{CP}\rangle, \quad |B^0\rangle \longrightarrow |\overline{B}^0\rangle \longrightarrow |f_{CP}\rangle$$



probabilty parametrization vs Δt : $\mathcal{P}(\Delta t, q) = \frac{e^{-\Delta t/\tau_{B^0}}}{4\tau_{B^0}}\left[1 + q\left(\mathcal{A}_{CP}\cos\Delta m_d \Delta t + \mathcal{S}_{CP}\sin\Delta m_d \Delta t\right)\right]$

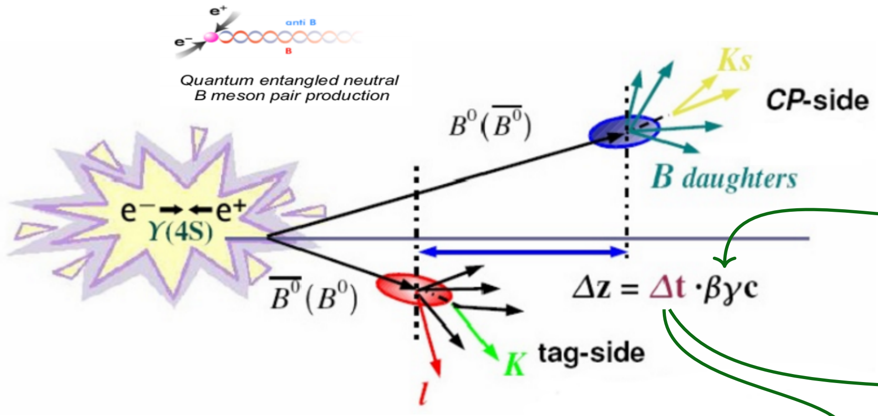


Fully reconstructed CP eigenstate (*e.g.* $J/\psi K^0_S$)

Flavour tagging

probabilty parametrization vs Δt : $\mathcal{P}(\Delta t, q) = \frac{e^{-\Delta t/\tau_{B^0}}}{4\tau_{B^0}}[1 + q(\mathcal{A}_{CP} \cos \Delta m_d \Delta t + \mathcal{S}_{CP} \sin \Delta m_d \Delta t)]$

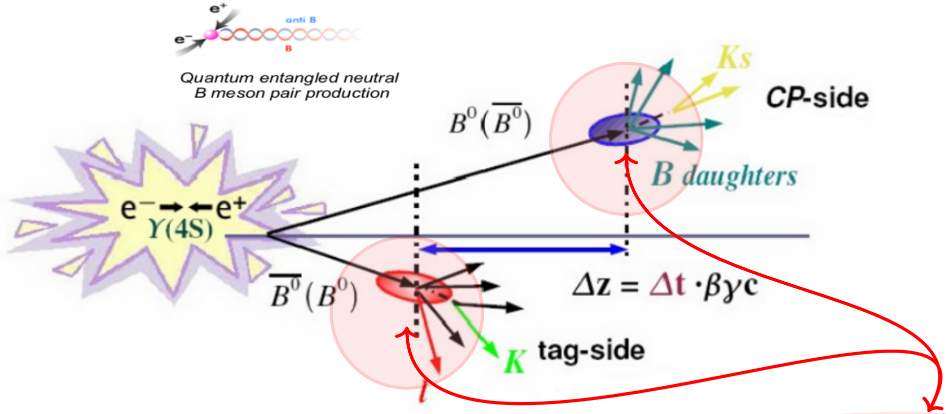
Time Dependent $\not{C}\not{P}$ Violation Measurements



$\beta\gamma =$
0.28 (0.45)
Belle2 (Belle)

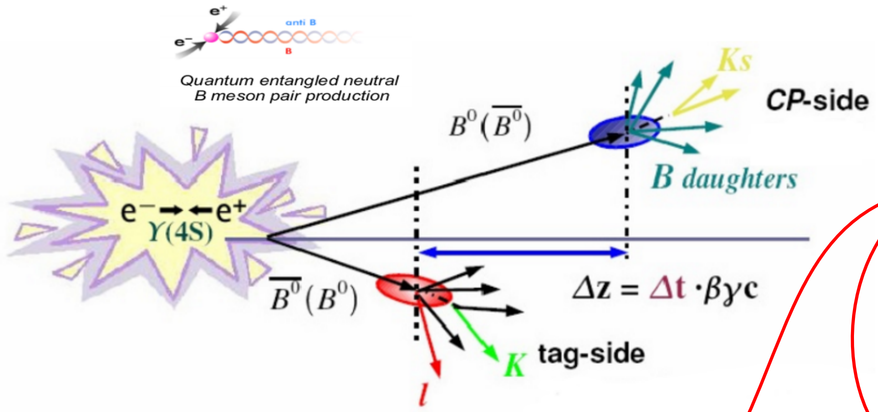
probabilty parametrization vs Δt : $\mathcal{P}(\Delta t, q) = \frac{e^{-\Delta t/\tau_{B^0}}}{4\tau_{B^0}}\left[1 + q\left(\mathcal{A}_{CP}\cos\Delta m_d\Delta t + \mathcal{S}_{CP}\sin\Delta m_d\Delta t\right)\right]$

Time Dependent $\not{CP}$ Violation Measurements



Signal and Tag-side
vertex resolution

Time Dependent $\not{C}\not{P}$ Violation Measurements



- signal x feed
- Background
  - Continuum
  - Peaking
- ML fit to extract the physical params
- Toys to project sensitivity
- Systematics (where dominant)
- ...

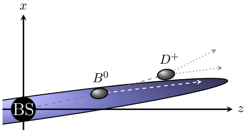
probabilty parametrization vs Δt : $\mathcal{P}(\Delta t, q) = \frac{e^{-\Delta t/\tau_{B^0}}}{4\tau_{B^0}} [1 + q(\mathcal{A}_{CP} \cos \Delta m_d \Delta t + \mathcal{S}_{CP} \sin \Delta m_d \Delta t)]$

Vertex resolution: on $B^0 \to J/\psi K^0_S$

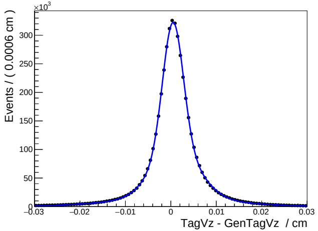
Vertex fit:

RAVE Adaptive Vertex Fit algo [CMS NOTE 2008/033]

down weights dynamically outliers (but those from K^0_S), no hard cut-off

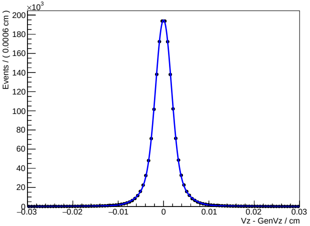


Δz resolution Tag-side



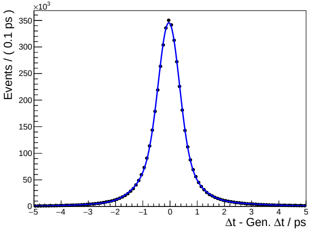
	Belle	Belle II
Bias	$29 \mu m$	$6 \mu m$
Resolution	$89 \mu m$	$53 \mu m$

Δz resolution $J/\psi \to \mu\mu$



	Belle	Belle II
Bias	$0.2 \mu m$	$2 \mu m$
Resolution	$43 \mu m$	$26 \mu m$

Δt resolution



	Belle	Belle II
Bias	$0.2\ ps$	$-0.03\ ps$
Resolution	$0.92\ ps$	$0.77\ ps$

Better resolution in spite of reduced boost

Flavour tagger

Many different final states considered, combined with MVA method.

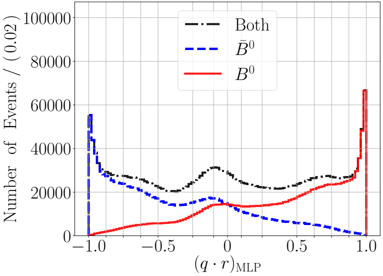
Categories	Targets
Electron	e^-
Int. Electron	e^+
Muon	μ^-
Int. Muon	μ^+
KinLepton	l^-
Int. KinLepton	l^+
Kaon	K^-
KaonPion	K^-, π^+
SlowPion	π^+
MaximumP*	l^-, π^-
FSC	l^-, π^+
FastPion	π^-
Lambda	Λ

$\overline{B}^0 \to D^{*+}\ \overline{\nu}_\ell\ \ell^-$
$\quad \hookrightarrow D^0\ \pi^+$
$\quad\quad \hookrightarrow X\ K^-$

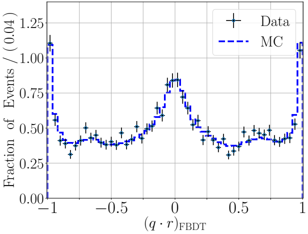
$\overline{B}^0 \to D^+\ \pi^-$
$\quad \hookrightarrow K^0\ \nu_\ell\ \ell^+$

$\overline{B}^0 \to \Lambda_c^+\ X^-$
$\quad \hookrightarrow \Lambda\ \pi^+$
$\quad\quad \hookrightarrow p\ \pi^-$

Belle II



Belle Data - MC comparison of BII algo



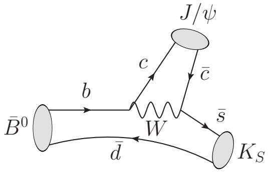
More than 10% efficiency increase on the same Belle dataset

effective efficiency

- **Belle II MC** $\quad 37.16 \pm 0.03\%$;
- Belle Data (assuming linearity) $\quad 33.6 \pm 0.5\%$;
- Belle MC $\quad 34.18 \pm 0.03\%$;
- Belle Data Old FT $\quad 30.1 \pm 0.4\%$;

Outline

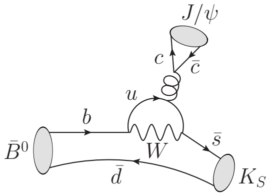
ϕ_1 in tree dominated $b \to c\bar{c}s$ transitions: $B^0 \to J/\psi K^0_S$



Decay dominated by a single weak phase small pengiun pollution

$S \simeq \sin(2\phi_1)$

Penguin contribution



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

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

Current status from Belle *[PRL 108 171802]*					**Belle II expected uncertainties @ 50 ab^{-1}**			
uncertainties (10^{-3})		*Value*	*stat*	*syst*	*stat*	*syst: reducible*	*irreducible*	
$J/\psi K^0_S$	S	+0.670	29	13	3.5	1.2	8.2	4.4
	$\mathcal{A} \equiv -C$	-0.015	21	+45,-23	2.5	0.7	+43,-22	+42, - 11
$b \to c\bar{c}s$	S	+0.667	23	12	2.7	2.6	7.0	3.6
	$\mathcal{A} \equiv -C$	+0.006	16	12	1.9	1.4	10.6	8.7

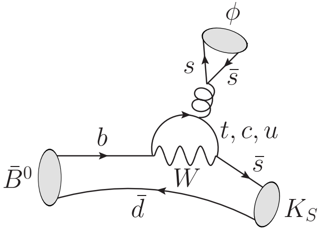
Precision better than 1% is expected on ϕ_1 from $b \to c\bar{c}s$

ϕ_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

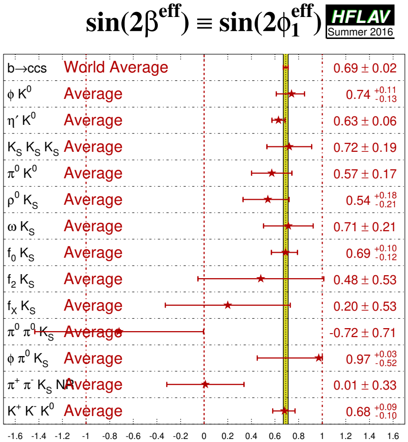


Motivations:

- probes ϕ_1 through different vertices;
- many different final states;
- more sensitive to new physics in the loop;
- tree/box pollution present but different predictions available

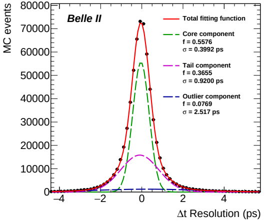
Current status:

All measurement are statistically limited

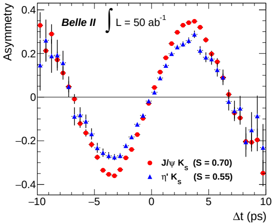


$b \to q\bar{q}s$ transitions: $B^0 \to \phi K^0$ and $B^0 \to \eta' K^0$

$B^0 \to \phi K^0_S$ Δt resolution



$Asym_{CP}(\Delta t)$



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

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

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

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

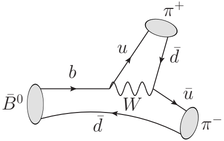
  - $(\sigma_{stat} \sim \sigma_{syst})$ around $\sim 10 - 20$ ab^{-1}

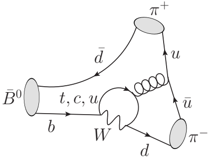
- competition with LHCb for ϕK^0_S, not for $\eta' K^0$

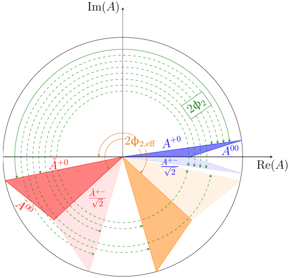
Outline

ϕ_2/α from $B^0 \to \pi\pi$

Two amplitudes of comparable size with different weak phase:







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

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

Isospin analysis[Gronau-London PRL, 64 3381 (1990)]: constraints B^0 and $B^\pm$ amplitudes:

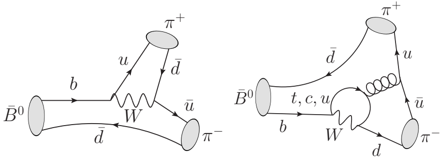
$$A^{+0} = A^{+-}/\sqrt{2} + A^{00}$$
$$\bar{A}^{+0} = \bar{A}^{+-}/\sqrt{2} + \bar{A}^{00}$$
$$|A^{+0}| = |\bar{A}^{+0}|$$

need to measure TDCPV all modes: π^{+-}, π^{00}

- magnitude and phase of $\overset{(-)}{A}{}^{+-}$ from $B^0 \to \pi^+\pi^-$;
- magnitude of $\overset{(-)}{A}{}^{00}$ from $\mathcal{B}$ and $\mathcal{C}_{00}$ of $B^0 \to \pi^0\pi^0$
  - no phase ($\mathcal{S}_{00}$): triangles can flip
  - 8-fold ambiguity in $\phi_2(\alpha)$
- need $\mathcal{S}_{00}$ (TDCPV) for $B^0 \to \pi^0\pi^0$ to solve ambiguity.

ϕ_2/α from $B^0 \to \pi\pi$

Two amplitudes of comparable size with different weak phase:



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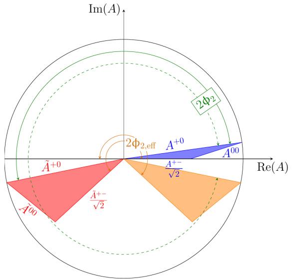

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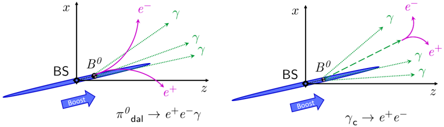
  - no phase ($\mathcal{S}_{00}$): triangles can flip
  - 8-fold ambiguity in $\phi_2(\alpha)$
- need $\mathcal{S}_{00}$ (TDCPV) for $B^0 \to \pi^0\pi^0$ to solve ambiguity.

ϕ_2 measurement: $B \to \pi^0\pi^0$ sensitivity

First attempt to measure $S_{\pi^0\pi^0}$

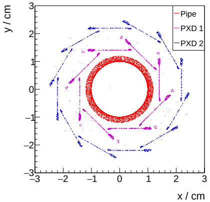
Final state	$\mathcal{BR}(\%)$	ev. yield for 50 ab^{-1}
$\pi^0_{\gamma\gamma}(\to \gamma\gamma)\ \pi^0_{\gamma\gamma}(\to \gamma\gamma)$	98.823	
$\pi^0_{dal}(\to e^+e^-\gamma)\ \pi^0_{\gamma\gamma}(\to \gamma\gamma)$	1.174	270
$\pi^0_{\gamma_c\gamma}(\to \gamma_c(\to e^+e^-)\gamma)\ \pi^0_{\gamma\gamma}(\to \gamma\gamma)$	-	50

Dalitz decay or conversion



(e^+e^-) and B^0 direction to reconstruct vertex

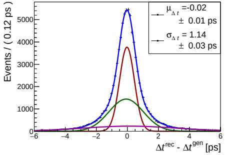
Conversion vertices in the innermost part of detector



Δt resolution

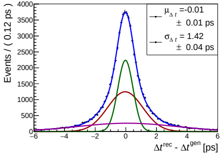
Pure Dalitz

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



Converted

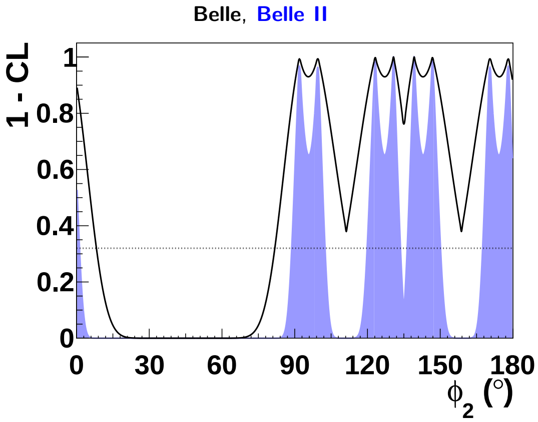
$\delta(\Delta t) = 1.42 \pm 0.04$ ps



Dalitz decays and γ conversions reconstructed as Dalitz candidates can be separated on a statistical basis

ϕ_2/α sensitivity from $B^0 \to \pi\pi$

- **Isospin analysis input in $B \to \pi\pi$**
- current results (black line)
  - Belle [arXiv:1705.02083][PRD 87(3) 031103][PRD 88(9) 092003]
  - Today $\sigma_{\phi_2}^{Belle\ exp} = \pm 15^\circ$
    - ★ no results for $S_{\pi^0\pi^0}$
  - (WA including $\pi\pi, \rho\rho, \rho\pi$: $\sigma_{\phi_2}^{WA\ exp} = {}^{+4.4}_{-4.0}{}^\circ$)
- expected results from Belle II with 50 ab^{-1} (blue area)
  - from improvement on already existing results



ϕ_2/α sensitivity from $B^0 \to \pi\pi$

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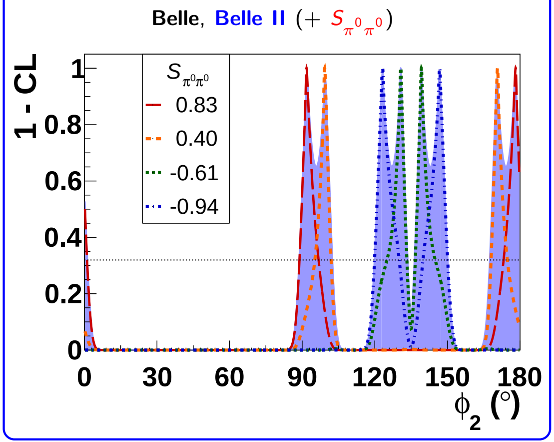
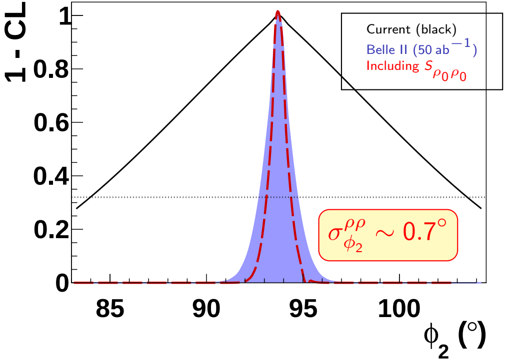
- expected results from Belle II with 50 ab^{-1} (blue area)
  - from improvement on already existing results
- Adding $S_{\pi^0\pi^0}$ input (color lines)
  - $\Delta\phi^{exp}_{2,\pi\pi}|^{88^\circ}_{1\sigma} \sim 2^\circ$
  - different solution depending on the actual value of $S_{\pi^0\pi^0}$
    - four different hypotesis shown



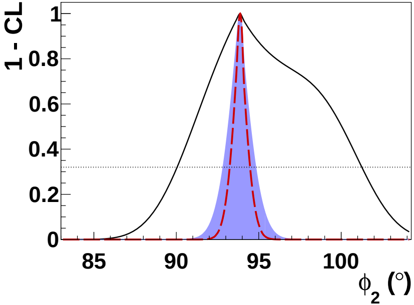
ϕ_2/α from $B^0 \to \rho\rho$ and combined $B^0 \to \pi\pi,\ \rho\rho$

only $B \to \rho\rho$

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



Combining $B \to \pi\pi$ and $\rho\rho$



Combined: $\sigma_{\phi_2}(\pi\pi,\rho\rho) \sim 0.6°$

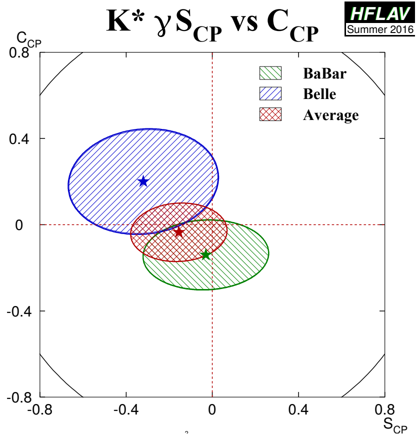
Outline

1. Introduction
   - Unitary triangle
   - SuperKEKB and Belle II
2. Time Dependent $\not{CP}$ Violation Measurements
3. ϕ_1/β measurement
   - $b \to c\bar{c}s$ transition
   - $b \to q\bar{q}s$ transition
4. ϕ_2/α measurement
   - $\mathrm{B} \to \pi\pi$
   - $\mathrm{B} \to \rho\rho$
5. New Physics with TDCPV
   - $\mathrm{B}^0 \to \mathrm{K}^0_S \pi^0 \gamma$
6. Conclusion and outlook

Probing New Physics with $b \to s\gamma$: $B^0 \to K^0_S \pi^0 \gamma$

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 $B^0 \to \overline{B}^0 \to f_{CP}\gamma_R$ only for helicity suppressed $b \to s\gamma_R$ decay
- TDCPV analysis is sensitive to the decay rate of b into "wrongly" polarized γ.
- prediction:
  $S^{SM}_{K^0_S\pi^0\gamma} \sim -2\frac{m_s}{m_b}\sin 2\phi_1 = -(2.3 \pm 1.6)\%$ [PRD75,054004(2007)]
- current results: $S^{exp}_{K^0_S\pi^0\gamma} = -0.16 \pm 0.22$ [HFLAV 2018]
- New physics can enhance the $b \to s\gamma_R$ decay rate



- BaBar ($N_{B\overline{B}} = 467 \cdot 10^6$) [PRD 78 (2008) 071102]
- Belle ($N_{B\overline{B}} = 535 \cdot 10^6$) [PRD 74 (2006) 111104(R)]

Probing New Physics with $b \to s\gamma$: $B^0 \to K^0_S \pi^0 \gamma$

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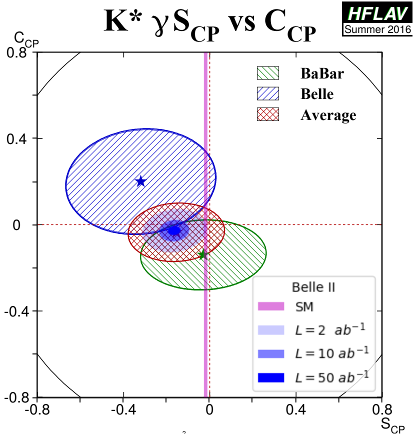
- New physics can enhance the $b \to s\gamma_R$ decay rate
- Interesting at Belle II already with few ab^{-1}



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- Belle ($N_{B\overline{B}} = 535 \cdot 10^6$) [PRD 74 (2006) 111104(R)]
- **Belle II: $\mathbf{L = 2, 10, 50\ ab^{-1}}$**

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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;

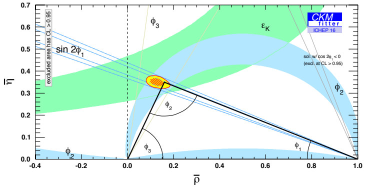
$\phi_3 = \gamma$ will improve by $\mathcal{O}(10)$, strong competition with LHCb;

NP Probe for NP in TDCPV $B^0 \to K^0_S \pi^0 \gamma$

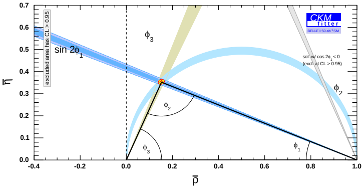
- More information on B2TIP report

CPV only input

Current world average



Belle II projection @ 50ab^{-1}



Conclusion and outlook

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  - large dataset with an improved detector and algorithms.
  - unique possibilities for modes with final states with neutrals
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NP Probe for NP in TDCPV $B^0 \to K^0_S \pi^0 \gamma$

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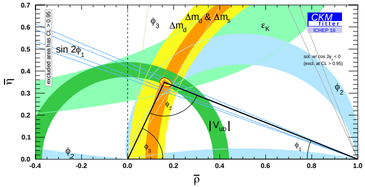
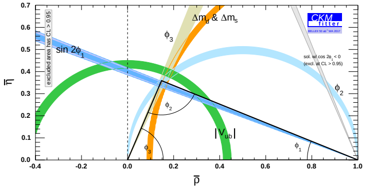
All input

Current world average



Belle II projection @ 50ab^{-1}



Conclusion and outlook

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$\phi_1 =$

$\phi_2 =$

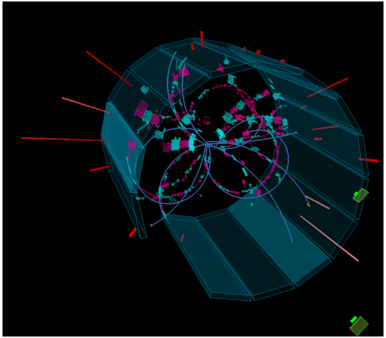
$\phi_3 =$

N

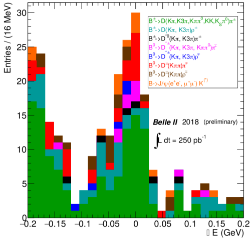
  - I

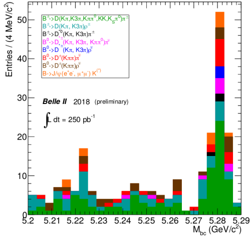
First SuperKEKB collision on April 26^{th}:

$B\,\overline{B}$ like event

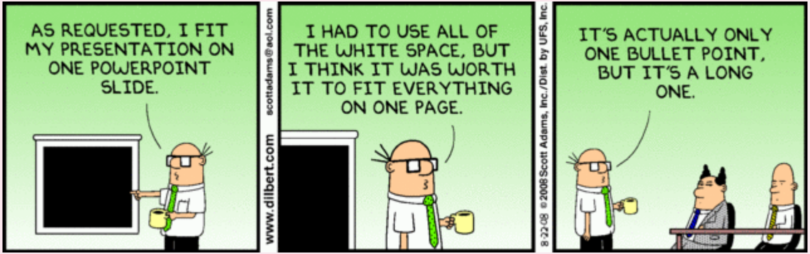


B-factory are back in the game

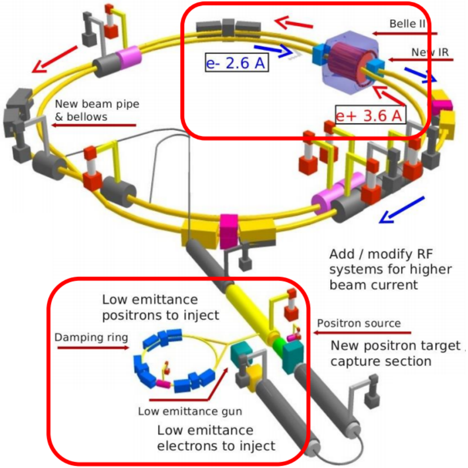


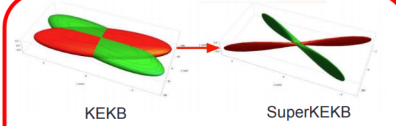


Additional or backup slides



- SuperKEKB is successor of former KEKB but refurbished with the new design





“nano-beam” scheme

Beam squeezing: x20 smaller at IR

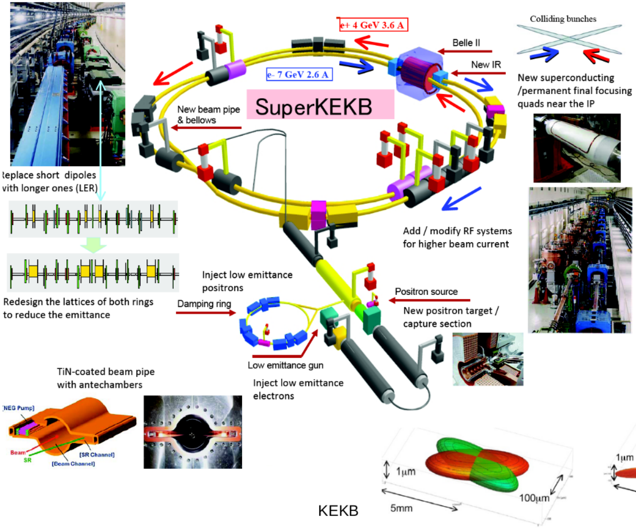
$$\textbf{Luminosity} = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \zeta_{\pm y}}{\beta_y^*}\frac{R_L}{R_y}$$

x2 ($I_\pm$)

X1/20 (β_y^*)

Target luminosity: $8\text{x}10^{35}\text{cm}^{-2}\text{s}^{-1}$
KEKB x 40!

SuperKEKB: new generation B-factory



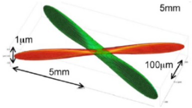
Peak luminosity

- KEKB = 2.11×10^{34} cm^{-2} s^{-1}
- SuperKEKB = 8×10^{35} cm^{-2} s^{-1}

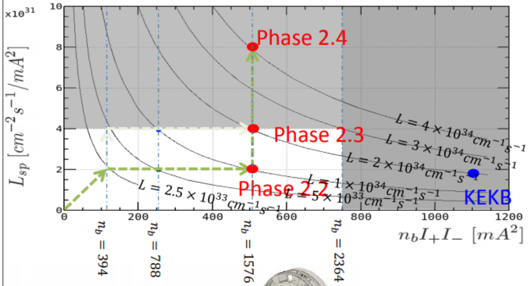
e^+e^- beams energy

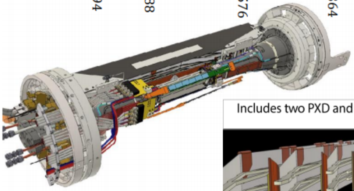
- KEKB = 8 GeV / 3.5 GeV
- SuperKEKB = 7 GeV / 4 GeV

SuperKEKB Nanobeam

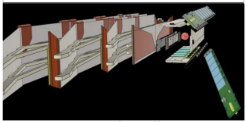


Phase 2 commissioning



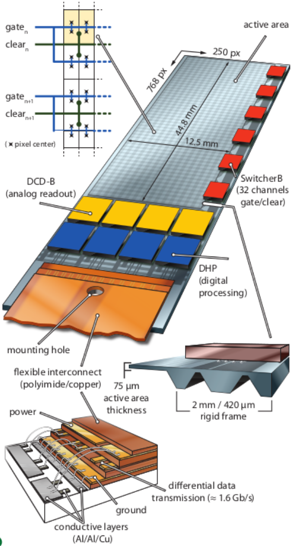


Includes two PXD and four SVD ladders



- 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}

Pixel Detector



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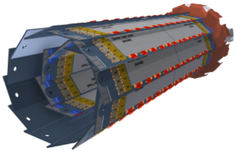
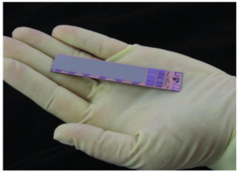




- Inst. Lumi.: $\mathcal{L}_{\text{Belle II}} \sim 40 \cdot \mathcal{L}_{\text{Belle}}$

$\Rightarrow$ Background $\uparrow\uparrow\uparrow$

- Closest to IP

$\Rightarrow$ Occupancy $(\sim r^{-2})$ $\uparrow\uparrow\uparrow$

- $\langle\beta\gamma\rangle_{\text{Belle II}} < \langle\beta\gamma\rangle_{\text{Belle}}$

$\Rightarrow$ smaller Δz

$\Rightarrow$ Pixel Detector needed !

$\Rightarrow$ DEPFET Technology most suited
DEPleted Field Effect Transistor

$\sin(2\beta)$ in $b \to c\bar{c}s$ transitions

systematics from Belle

		$J/\psi K_S^0$	$\psi(2S)K_S^0$	$\chi_{c1}K_S^0$	$J/\psi K_L^0$	All
Vertexing	$\mathcal{S}_f$	±0.008	±0.031	±0.025	±0.011	±0.007
	$\mathcal{A}_f$	±0.022	±0.026	±0.021	±0.015	±0.007
Δt resolution	$\mathcal{S}_f$	±0.007	±0.007	±0.005	±0.007	±0.007
	$\mathcal{A}_f$	±0.004	±0.003	±0.004	±0.003	±0.001
Tag-side interference	$\mathcal{S}_f$	±0.002	±0.002	±0.002	±0.001	±0.001
	$\mathcal{A}_f$	$^{+0.038}_{-0.000}$	$^{+0.038}_{-0.000}$	$^{+0.038}_{-0.000}$	$^{+0.000}_{-0.037}$	±0.008
Flavor tagging	$\mathcal{S}_f$	±0.003	±0.003	±0.004	±0.003	±0.004
	$\mathcal{A}_f$	±0.003	±0.003	±0.003	±0.003	±0.003
Possible fit bias	$\mathcal{S}_f$	±0.004	±0.004	±0.004	±0.004	±0.004
	$\mathcal{A}_f$	±0.005	±0.005	±0.005	±0.005	±0.005
Signal fraction	$\mathcal{S}_f$	±0.004	±0.016	< 0.001	±0.016	±0.004
	$\mathcal{A}_f$	±0.002	±0.006	< 0.001	±0.006	±0.002
Background Δt PDFs	$\mathcal{S}_f$	< 0.001	±0.002	±0.030	±0.002	±0.001
	$\mathcal{A}_f$	< 0.001	< 0.001	±0.014	< 0.001	< 0.001
Physics parameters	$\mathcal{S}_f$	±0.001	±0.001	±0.001	±0.001	±0.001
	$\mathcal{A}_f$	< 0.001	< 0.001	±0.001	< 0.001	< 0.001
Total	$\mathcal{S}_f$	±0.013	±0.036	±0.040	±0.021	±0.012
	$\mathcal{A}_f$	$^{+0.045}_{-0.023}$	$^{+0.047}_{-0.027}$	$^{+0.046}_{-0.026}$	$^{+0.017}_{-0.041}$	±0.012

Systematic errors in $\mathcal{S}_f$ and $\mathcal{A}_f \equiv \mathcal{C}_f$ in each f_{CP} mode and for the sum of all modes [PRL 108 171802]

$b \to q\bar{q}s$ modes efficiencies

$B^0 \to \eta' K^0$

Channel	Strategy	ε	ε_{SxF}
$\eta'(\eta_{\gamma\gamma}\pi^{\pm})K_S^{(\pm)}$	C$\star$	23.0 %	3.8 %
$\eta'(\eta_{3\pi}\pi^{\pm})K_S^{(\pm)}$	A	6.7 %	2.6%
	B$\star$	8.0 %	6.0%
	C	9.5 %	28.6%

Efficiency and fraction of cross feed candidates for $\eta'(\eta_{\gamma\gamma}\pi^{\pm})K_S^{(\pm)}$ and $\eta'(\eta_{3\pi}\pi^{\pm})K_S^{(\pm)}$ channels when selecting only one (A), two (B), or all (C) the candidates in the event. The selected strategy is labeled with $\star$.

$B^0 \to \omega K^0$

$\omega(\pi^+\pi^-\pi^0)K_S^0(\pi^{\pm})$

L (ab^{-1})	yield	$\sigma(S)$	$\sigma(A)$
1	334	0.17	0.14
5	1670	0.08	0.06
50	16700	0.024	0.020

Extrapolated sensitivity for the ωK_S^0 mode. The Δt resolution is taken from the $\eta' K_S^0$ study, while we assume a reconstruction efficiency of 21%

$B^0 \to \phi K^0$

Channel	ε_{reco}	Yield	$\sigma(S_{\phi K^0})$	$\sigma(A_{\phi K^0})$
1 ab^{-1} lumi.:				
$\phi(K^+K^-)K_S^0(\pi^+\pi^-)$	35%	456	0.174	0.123
$\phi(K^+K^-)K_S^0(\pi^0\pi^0)$	25%	153	0.295	0.215
$\phi(\pi^+\pi^-\pi^0)K_S^0(\pi^+\pi^-)$	28%	109	0.338	0.252
K_S^0 modes combination			0.135	0.098
$K_S^0 + K_L^0$ modes combination			0.108	0.079
5 ab^{-1} lumi.:				
$\phi(K^+K^-)K_S^0(\pi^+\pi^-)$	35%	2280	0.078	0.055
$\phi(K^+K^-)K_S^0(\pi^0\pi^0)$	25%	765	0.132	0.096
$\phi(\pi^+\pi^-\pi^0)K_S^0(\pi^+\pi^-)$	28%	545	0.151	0.113
K_S^0 modes combination			0.060	0.044
$K_S^0 + K_L^0$ modes combination			0.048	0.035

Sensitivity estimates for $S_{\phi K^0}$ and $A_{\phi K^0}$ parameters. The efficiency ε_{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

Channel	$\int \mathcal{L}$	Event yield	$\sigma(S)$	$\sigma(S)_{2017}$	$\sigma(A)$	$\sigma(A)_{2017}$
$J/\psi K^0$	50 ab^{-1}	$1.4 \cdot 10^6$	0.0052	0.022	0.0050	0.021
ϕK^0	5 ab^{-1}	5590	0.048	0.12	0.035	0.14
$\eta' K^0$	5 ab^{-1}	27200	0.027	0.06	0.020	0.04
ωK^0_S	5 ab^{-1}	1670	0.08	0.21	0.06	0.14
$K^0_S \pi^0 \gamma$	5 ab^{-1}	1400	0.10	0.20	0.07	0.12
$K^0_S \pi^0$	5 ab^{-1}	5699	0.09	0.17	0.06	0.10

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:

$$\mathcal{P}^i_j = \underbrace{\mathcal{T}_j\left(\Delta t^i, \sigma^i_{\Delta t}, \eta^i_{CP}\right)}_{\text{time-dep part}} \prod_k \underbrace{\mathcal{Q}_{k,j}(x^i_k)}_{\text{time integrated}}$$

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_k) used, in addition to Δt

- M_{bc}
- ΔE
- Cont. Suppr.
- SxF BDT/helicity angles

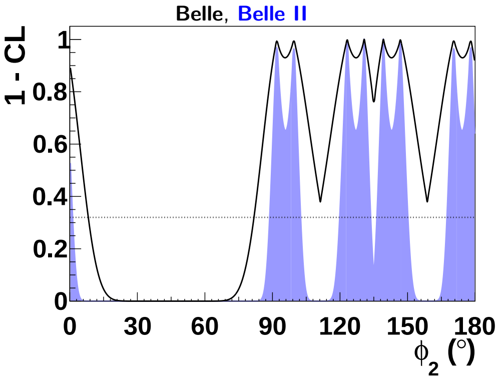
Parameters:

- effective tagging efficiency: $Q = \epsilon(1-2w)^2 = 0.33$
  - $w = 0.21$, $\Delta w = 0.02$
- Δt resolution (convoluted)
- τ, Δm from PDG

Isospin analysis input in B $\to \pi\pi$

	Value	Belle @ 0.8 ab^{-1}	Belle II @ 50 ab^{-1}
$\mathcal{B}_{\pi^+\pi^-}$ [10^{-6}]	5.04	$\pm 0.21 \pm 0.18$ [2]	$\pm 0.03 \pm 0.08$
$\mathcal{B}_{\pi^0\pi^0}$ [10^{-6}]	1.31	$\pm 0.19 \pm 0.18$ [1]	$\pm 0.04 \pm 0.04$
$\mathcal{B}_{\pi^+\pi^0}$ [10^{-6}]	5.86	$\pm 0.26 \pm 0.38$ [2]	$\pm 0.03 \pm 0.09$
$C_{\pi^+\pi^-}$	-0.33	$\pm 0.06 \pm 0.03$ [3]	$\pm 0.01 \pm 0.03$
$S_{\pi^+\pi^-}$	-0.64	$\pm 0.08 \pm 0.03$ [3]	$\pm 0.01 \pm 0.01$
$C_{\pi^0\pi^0}$	-0.14	$\pm 0.36 \pm 0.12$ [1]	$\pm 0.03 \pm 0.01$

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



ϕ_2/α sensitivity

Isospin analysis input in B $\rightarrow \pi\pi$

	Value	Belle @ 0.8 ab^{-1}	Belle II @ 50 ab^{-1}
$\mathcal{B}_{\pi^+\pi^-}$ [10^{-6}]	5.04	$\pm 0.21 \pm 0.18$ [2]	$\pm 0.03 \pm 0.08$
$\mathcal{B}_{\pi^0\pi^0}$ [10^{-6}]	1.31	$\pm 0.19 \pm 0.18$ [1]	$\pm 0.04 \pm 0.04$
$\mathcal{B}_{\pi^+\pi^0}$ [10^{-6}]	5.86	$\pm 0.26 \pm 0.38$ [2]	$\pm 0.03 \pm 0.09$
$C_{\pi^+\pi^-}$	-0.33	$\pm 0.06 \pm 0.03$ [3]	$\pm 0.01 \pm 0.03$
$S_{\pi^+\pi^-}$	-0.64	$\pm 0.08 \pm 0.03$ [3]	$\pm 0.01 \pm 0.01$
$C_{\pi^0\pi^0}$	-0.14	$\pm 0.36 \pm 0.12$ [1]	$\pm 0.03 \pm 0.01$
$S_{\pi^0\pi^0}$	—	—	$\pm 0.29 \pm 0.03$

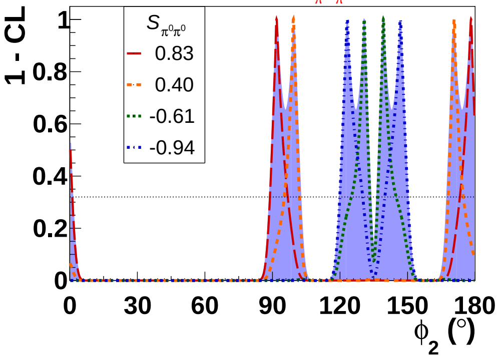
[1][arXiv:1705.02083], [2][PRD 87(3) 031103],[3][PRD 88(9) 092003]

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

$$\Delta\phi^{exp}_{2,\pi\pi}\big|^{88^\circ}_{1\sigma} \sim 2^\circ$$

Today $\sigma^{WA}_{\phi_2^{exp}} = {}^{+4.4}_{-4.0}{}^\circ$, $\quad \sigma^{Belle}_{\phi_2^{exp}} = \pm 15^\circ$

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



different solution depending on the actual value of $S_{\pi^0\pi^0}$

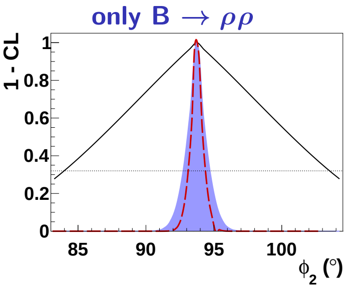
ϕ_2/α from $B^0 \to \rho\rho$

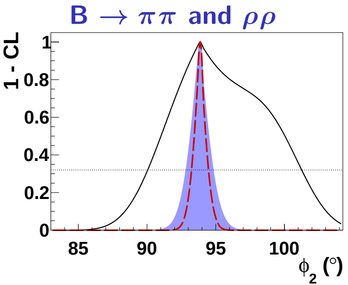
Similar to $B^0 \to \pi\pi$: only ρ_L to be used, $S_{\rho_0\rho_0}$ available (BaBar[4])
No ambiguity since $\mathcal{B}_{\rho^0\rho^0} \ll \mathcal{B}_{\rho^+\rho^-}$

	Value	0.8 ab^{-1}	50 ab^{-1}
$f_{L,\rho^+\rho^-}$	0.988	$\pm0.012 \pm 0.023$ [1]	$\pm0.002 \pm 0.003$
$f_{L,\rho^0\rho^0}$	0.21	$\pm0.20 \pm 0.15$ [2]	$\pm0.03 \pm 0.02$
$\mathcal{B}_{\rho^+\rho^-}$ [10^{-6}]	28.3	$\pm1.5 \pm 1.5$ [1]	$\pm0.19 \pm 0.4$
$\mathcal{B}_{\rho^0\rho^0}$ [10^{-6}]	1.02	$\pm0.30 \pm 0.15$ [2]	$\pm0.04 \pm 0.02$
$A_{\rho^+\rho^-}$	0.00	$\pm0.10 \pm 0.06$ [1]	$\pm0.01 \pm 0.01$
$S_{\rho^+\rho^-}$	-0.13	$\pm0.15 \pm 0.05$ [1]	$\pm0.02 \pm 0.01$
	Value	0.08 ab^{-1}	50 ab^{-1}
$f_{L,\rho^+\rho^0}$	0.95	$\pm0.11 \pm 0.02$ [3]	$\pm0.004 \pm 0.003$
$\mathcal{B}_{\rho^+\rho^0}$ [10^{-6}]	31.7	$\pm7.1 \pm 5.3$ [3]	$\pm0.3 \pm 0.5$
	Value	0.5 ab^{-1}	50 ab^{-1}
$A_{\rho^0\rho^0}$	-0.2	$\pm0.8 \pm 0.3$ [4]	$\pm0.08 \pm 0.01$
$S_{\rho^0\rho^0}$	0.3	$\pm0.7 \pm 0.2$ [4]	$\pm0.07 \pm 0.01$

[1][PRD93(3) 032010 (2016)] [2][PRD89, 119903 (2014)] [3][PRL91, 221801 (2003)] [4][PRD78, 071104 (2008)]

$\sigma^{\rho\rho}_{\phi_2} \sim 0.7^\circ$ (WA $\pm 5^\circ$) Combined: $\sigma_{\phi_2}(\pi\pi, \rho\rho) \sim 0.6^\circ$





ϕ_2 from isospin analysis $B^0 \to \rho\rho$, $B^0 \to \rho\pi$,

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

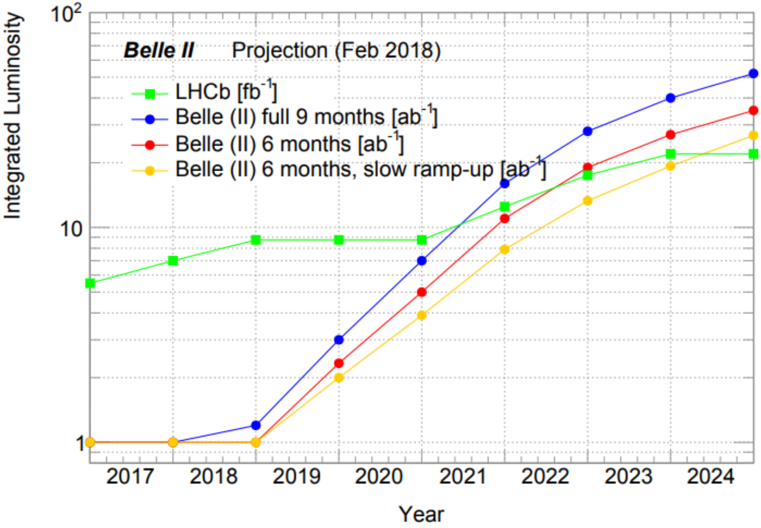
	Value	0.8 ab^{-1}	50 ab^{-1}
$f_{L,\rho^+\rho^-}$	0.988	$\pm 0.012 \pm 0.023$ [77]	$\pm 0.002 \pm 0.003$
$f_{L,\rho^0\rho^0}$	0.21	$\pm 0.20 \pm 0.15$ [83]	$\pm 0.03 \pm 0.02$
$\mathcal{B}_{\rho^+\rho^-}$ [10^{-6}]	28.3	$\pm 1.5 \pm 1.5$ [77]	$\pm 0.19 \pm 0.4$
$\mathcal{B}_{\rho^0\rho^0}$ [10^{-6}]	1.02	$\pm 0.30 \pm 0.15$ [83]	$\pm 0.04 \pm 0.02$
$C_{\rho^+\rho^-}$	0.00	$\pm 0.10 \pm 0.06$ [77]	$\pm 0.01 \pm 0.01$
$S_{\rho^+\rho^-}$	-0.13	$\pm 0.15 \pm 0.05$ [77]	$\pm 0.02 \pm 0.01$
	Value	0.08 ab^{-1}	50 ab^{-1}
$f_{L,\rho^+\rho^0}$	0.95	$\pm 0.11 \pm 0.02$ [68]	$\pm 0.004 \pm 0.003$
$\mathcal{B}_{\rho^+\rho^0}$ [10^{-6}]	31.7	$\pm 7.1 \pm 5.3$ [68]	$\pm 0.3 \pm 0.5$
	Value	0.5 ab^{-1}	50 ab^{-1}
$C_{\rho^0\rho^0}$	0.2	$\pm 0.8 \pm 0.3$ [67]	$\pm 0.08 \pm 0.01$
$S_{\rho^0\rho^0}$	0.3	$\pm 0.7 \pm 0.2$ [67]	$\pm 0.07 \pm 0.01$

$\sigma_{S_{00},C_{00}} \sim 0.2$ with 5 ab^{-1}
also improv. on $f_L B(B^0 \to \rho^+\rho^-)$ and $f_L B(B^+ \to \rho^+\rho^0)$ useful With 50 ab^{-1} $\sigma_{\phi_2} \sim 2.5^\circ$

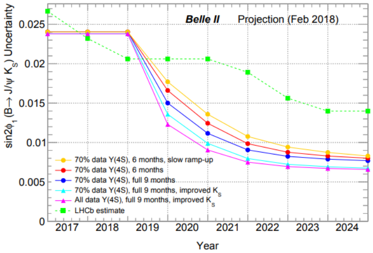
$B^0 \to \rho\pi$

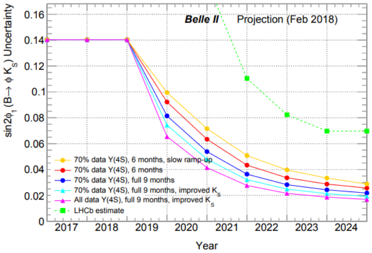
- Analysis done with Dalitz plot on $\pi^+\pi^-\pi^0$ final state.
- current analyses by BaBar and Belle suffer from low statistics
- which cause secondary solutions for ϕ_2 on both sides of primary
- and expected to vanish with larger dataset
- Strong motivation to repeat the analysis with at least few ab^{-1}
- No prediction available

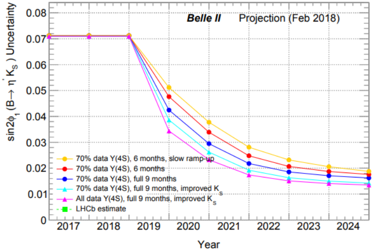
Competition with LHCb: luminosity



Competition with LHCb: ϕ_1





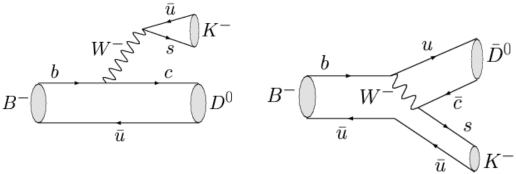


- $B \to \rho\rho$

7. ϕ_3/γ measurement
   - $B \to D(K^0_S\pi^+\pi^-)K^\pm$
   - V_{ub}

ϕ_3/γ measurement

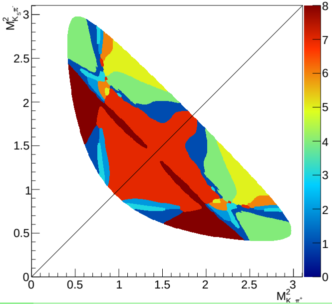
- ϕ_3/γ is the phase between $b \to c$ and $b \to u$
- from interference of tree-level diagrams
  - ✓ no B mixing, nor penguin pollution
    - ★ theoretical ambiguity very small
  - ✗ different strong phase
    - ★ today CLEO-c results [PRD82, 112006 (2010)]
    - ★ improvement from BESIII ($10\,\mathrm{fb}^{-1}$ @$\psi(3770)$)



interference if $D/\bar{D} \to f$ same final state

$B^\pm \to D[\to K^0_S\pi^+\pi^-]K^\pm$

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



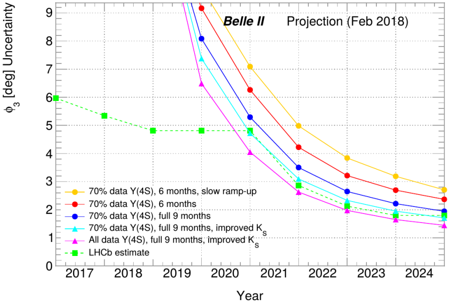
ϕ_3/γ sensitivity

Current status:

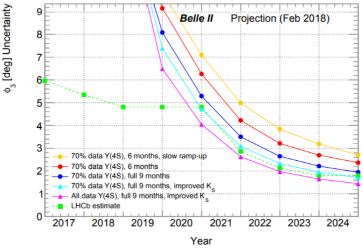
$$\phi_3^{Belle} = \left(78^{+15}_{-16}\right)^\circ \quad \phi_3^{LHCb} = \left(76.8^{+5.1}_{-5.7}\right)^\circ$$

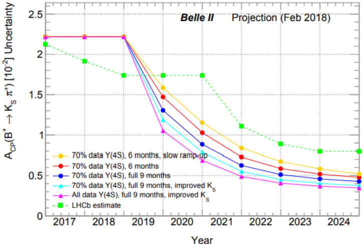
- sensitivity study on GGSZ $B^\pm \to D[\to K^0_S\pi\mu]K^\pm$
  - expected sensitivity to $\phi_3 \sim 3^\circ$ with $50\,\text{ab}^{-1}$
- improvement including:
  - **GGSZ** $D \to K^0_S K^+ K^-$ and $B^\pm \to D^* K^\pm$
  - **ADS/GLW** modes $B^\pm \to D^*[\to D\gamma\pi^0]K^\pm$
- LHCb will dominate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

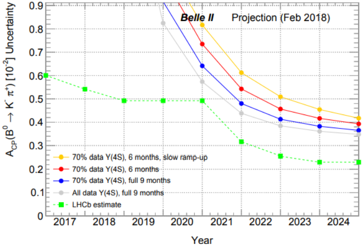
Projected ϕ_3 sensitivity for different luminosity profile scenarios



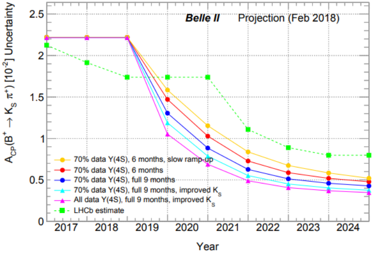
Competition with LHCb: ϕ_3

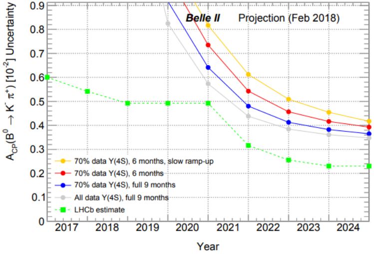






Competition with LHCb: Direct CPV



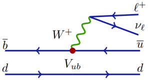


Vub: inclusive exclusive

- $|V_{ub}|$ can be measured via exclusive or inclusive semileptonic B decay.
- long standing 3σ tension between the two measurements
  - $|V_{ub}^{excl}| = (3.67 \pm 0.09(\text{exp}) \pm 0.12(\text{theo})) \times 10^{-3}$ vs $|V_{ub}^{incl}| = (4.52 \pm 0.15(exp) \pm 0.11(\text{theo})) \times 10^{-3}$

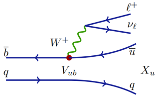
exclusive

- most promising channel is $B \to \pi \ell \nu$
- $\frac{d\Gamma}{dq^2} = \frac{G_F^2 |V_{ub}|^2}{24\pi^3} p_\pi^3 |f_+^{B\pi}(q^2)|^2$



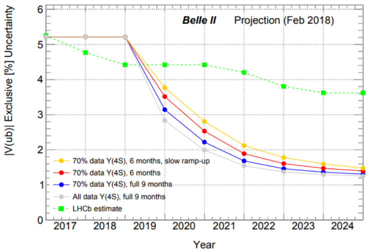
- $f^{B\pi}$ form factor (theo) limits precision
  - **Tagged**: fully reconstruct B companion, good q^2 resolution, low $\varepsilon \sim 0.55\%(0.3\%\text{Belle})$
  - expected precision 1.3%
  - **Untagged**: indirect determination of B companion: bad q^2 resolution, good $\varepsilon \sim 20\%(11\%\text{Belle})$
  - expected precision 1.7%

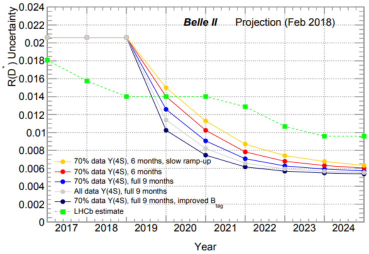
inclusive

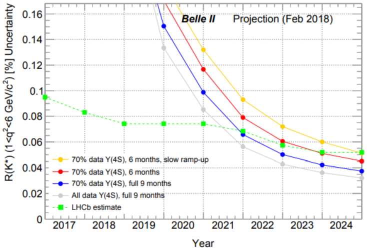


- From measurement of total or partial inclusive semileptonic branching decay rate $b \to u\ell\nu$
- fully rec tag-side, ℓ in signal side
- fit $B \to X_u \ell \nu$ rates with model from simualtion
  - limiting factor is modelling the dynamic of the decaying b quark
  - using $B \to X_s \gamma$ to study dynamic
- expected precision: 3.4(3)% @5(50) ab^{-1}

Competition with LHCb: V_{ub}







Bibliography I