First look at time-dependent CP violation using early Belle II data

Stefano Lacaprara
on behalf of Belle II collaboration

stefano.lacaprara@pd.infn.it

INFN Padova

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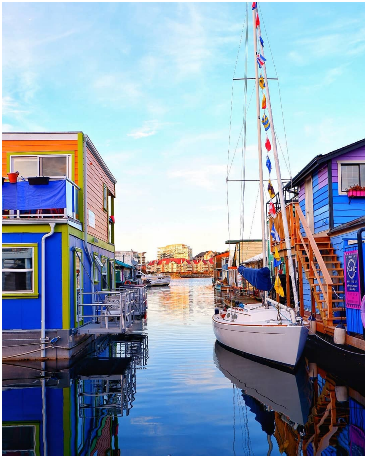
Photo Credit: Tourism Victoria

Outline

1. Introduction
   - CPV and CKM 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
   - $B \to \pi\pi$
5. New Physics with TDCPV
   - $B^0 \to K^0_S \pi^0 \gamma$
6. Conclusion and outlook



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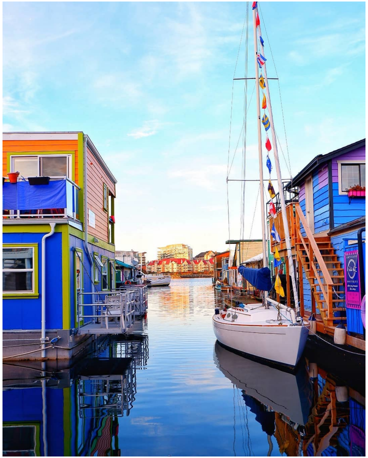
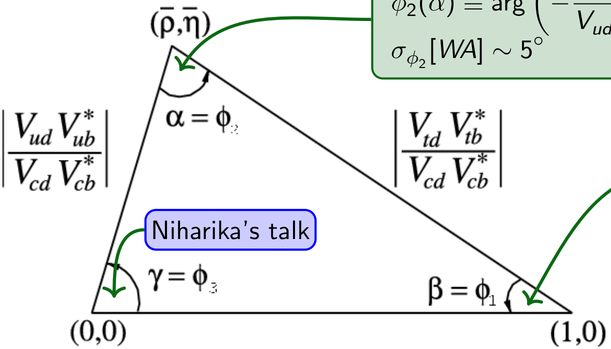


CPV and the CKM Unitarity Triangle

- CPV in SM is due to weak interaction, described in the quark sector by the V_{CKM} matrix
- B^0-system exhibits the largest CPV in the SM
- Unitarity requires: $\Sigma_k V^*_{ki} V_{kj} = \delta_{ij}$ so $V_{ud} V^*_{ub} + V_{cd} V^*_{cb} + V_{td} V^*_{tb} = 0$
  - CKM Unitarity Triangle;

$$V_{CKM} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$

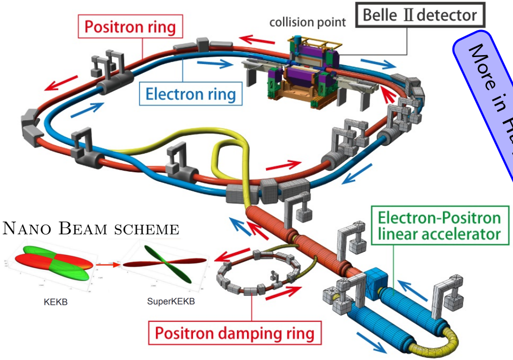
$$\phi_2(\alpha) \equiv \arg\left(-\frac{V_{td} V^*_{tb}}{V_{ud} V^*_{ub}}\right)$$
$\sigma_{\phi_2}[WA] \sim 5^\circ$



$$\phi_1(\beta) \equiv \arg\left(-\frac{V_{cd} V^*_{cb}}{V_{td} V^*_{tb}}\right)$$
$\sigma_{\phi_1}[WA] \sim 1^\circ$

Time Dependent $\not{CP}$ analysis in B^0 provide measurement of ϕ_1 and ϕ_2

$e^- \; e^+$ asymmetric collider at $\sqrt{s}$ of $\Upsilon(4S)$



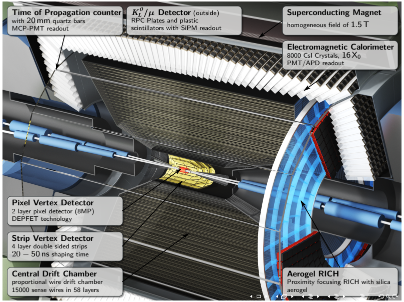
More in Hulya's talk on Friday

$\mathcal{L} \sim 8 \cdot 10^{35}$ (x40 KEKB/Belle)

$\int \mathcal{L} dt = 50\,\mathrm{ab}^{-1}$ (x50)

$\beta\gamma = 0.28$ (0.45 at KEKB/Belle)

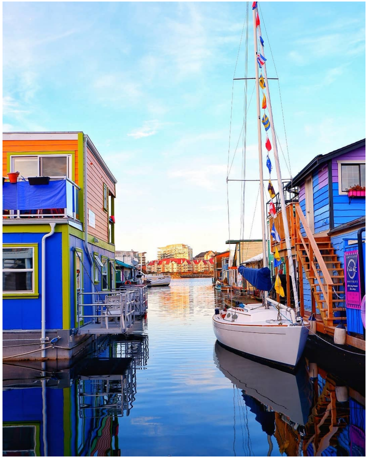
Major upgrade of Belle apparatus for all detectors



Key elements for TDCPV

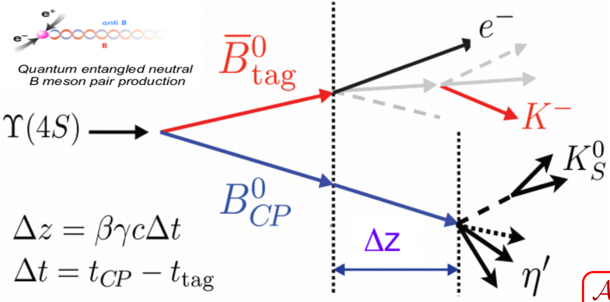
- New, extended **Vertex** detector (PVD+SVD)
- **CDC**: smaller cell size and longer lever arm
- **TOP-ARICH** New Particle ID detector for K/π separation
- new electronics for **KLM, ECL**, ...

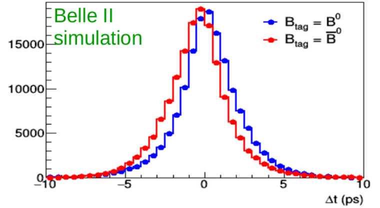
Outline



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

Key analysis technique at B-factories: coherent state of B pairs from the $\Upsilon(4S)$ decay





Belle II(Belle) $\langle \Delta z \rangle = 130(200)\ \mu m$

keys: Vertexing, Flavour Tagging

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

Direct CPV

$|B\rangle \longrightarrow |f\rangle$

$\neq$

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

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

mixing induced CPV

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

$|B^0\rangle \rightarrow |\overline{B}^0\rangle \rightarrow |f_{CP}\rangle$

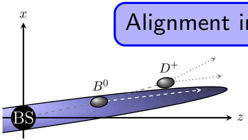
$$Asym_{CP}(\Delta t) = \frac{\Gamma(\overline{B}(\Delta t) \to f_{CP}; \Delta t) - \Gamma(B(\Delta t) \to f_{CP}; \Delta t)}{\Gamma(\overline{B}(\Delta t) \to f_{CP}; \Delta t) + \Gamma(B(\Delta t) \to f_{CP}; \Delta t)} = (\mathcal{A}_{CP} \cos \Delta m_d \Delta t + \mathcal{S}_{CP} \sin \Delta m_d \Delta t)$$

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

Vertex fit:

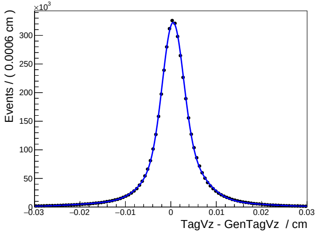
RAVE Adaptive Vertex Fit algo [CMS NOTE 2008/033]

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



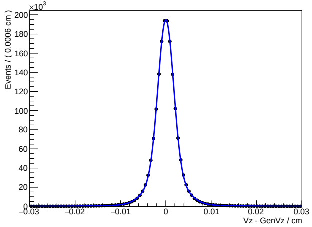
Alignment in Jakub's talk tomorrow

Δz resolution Tag-side



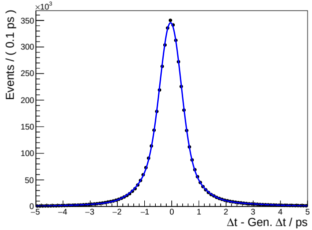
	Belle	Belle II
Bias	29μm	6μm
Resolution	89μm	53μm

Δz resolution $J/\psi \to \mu\mu$



	Belle	Belle II
Bias	0.2μm	2μm
Resolution	43μm	26μm

Δt resolution

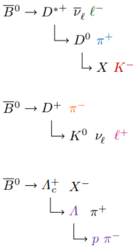


	Belle	Belle II
Bias	0.2 *ps*	−0.03 *ps*
Resolution	0.92 *ps*	0.77 *ps*

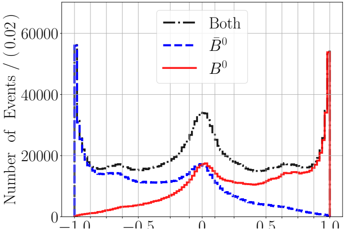
Better resolution in spite of reduced boost ($\beta\gamma = 0.28(0.45)$)

Many different final states considered, combined with two layers of MVA discriminators.

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

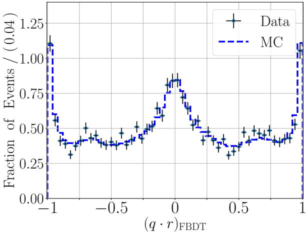


Belle II - MC



q(tag value=± 1)$\cdot r$(dilution factor)

Belle Data - MC comparison of BII algo

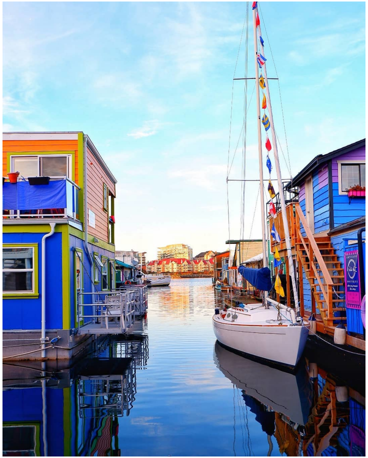


effective tagging efficiency: $\varepsilon_{eff} = \Sigma_i \varepsilon_i (1 - 2w_i)^2$

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

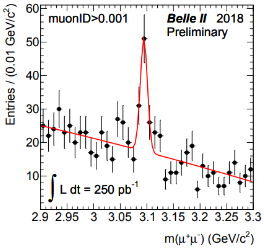
More than 10% efficiency increase on the same Belle dataset. Better algorithm and better PID

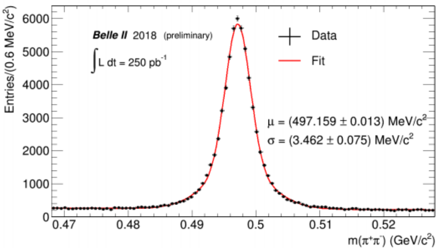
Outline

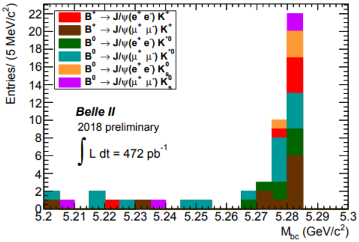


ϕ_1 in tree dominated $b \to c\bar{c}s$ transitions: $B^0 \to J/\psi K^0_S$

Decay dominated by a single weak phase small penguin pollution, $S \simeq \sin(2\phi_1)$







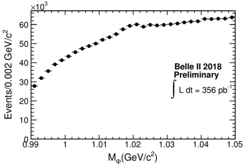
Current status from Belle [PRL 108 171802]					Belle II expected uncertainties @ 50 ab^{-1}			
uncertainties (10^{-3})		Value	stat	syst	stat	syst: reducible	irreducible	
$J/\psi K^0_S$	S	+0.670	29	13	3.5	1.2	8.2	4.4
	$\mathcal{A} \equiv -C$	-0.015	21	+45,-23	2.5	0.7	+43,-22	+42, - 11
$b \to c\bar{c}s$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

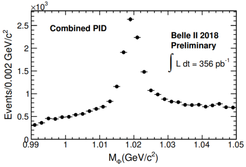
Precision better than 0.2° is expected on ϕ_1 from $b \to c\bar{c}s$

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

Gluonic penguin: NP in the loop?

Phase II: $\phi \to KK$ w/o and w/ PID

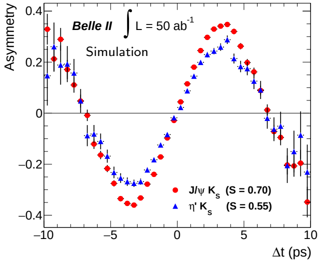


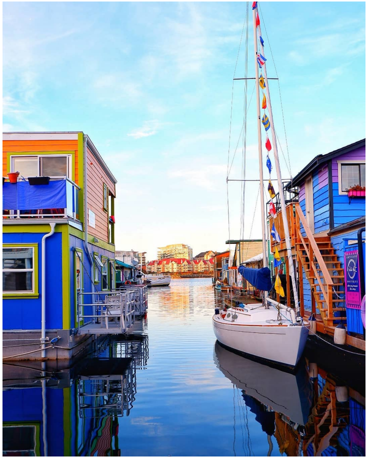


- **ϕK^0 ("an old superstar" A.J.Buras):**
  - Particle ID crucial
  - $(\phi \to K^+K^-/\pi^+\pi^-\pi^0) + (K^0_S/K^0_L)$
  - **WA** $\sigma_S = 0.12$, $\sigma_C = 0.14$
  - **5 ab^{-1}** $\sigma_S = 0.048$, $\sigma_C = 0.035$
  - **50 ab^{-1}** $\sigma_S = 0.020$, $\sigma_C = 0.011$ stat dominated

- **$\eta' K^0$:**
  - 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 $\sim 10 - 20\,\text{ab}^{-1}$
- competition with LHCb for ϕK^0_S, not for $\eta' K^0$

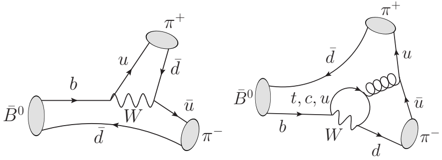
TDCPV with 50 ab^{-1} $B^0 \to J/\psi(\eta')K^0_S$





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 $B^\pm \to \pi^\pm\pi^0$

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

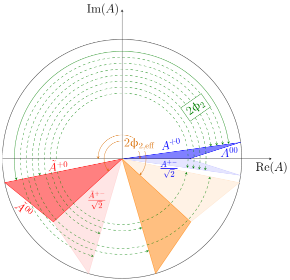
Isospin analysis[Gronau-London PRL, 64 3381 (1990)]: constraints B^0 and $B^\pm$ amplitudes:

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

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

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

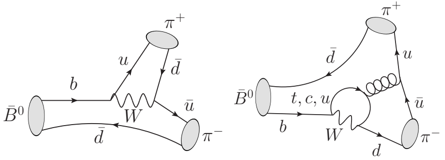
need to measure TDCPV all modes: π^{+-}, π^{00}



- 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 $\phi_2(\alpha)$

ϕ_2/α from $B^0 \to \pi\pi$

Two amplitudes of comparable size with different weak phase:



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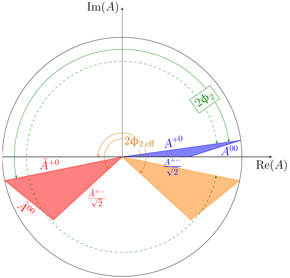

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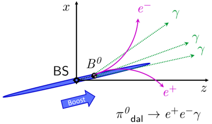
- magnitude of $\overset{(-)}{A}{}^{00}$ from $\mathcal{B}$ and $\mathcal{C}_{00}$ of $B^0 \to \pi^0\pi^0$
  - no phase ($\mathcal{S}_{00}$): triangles can flip
  - 8-fold ambiguity in $\phi_2(\alpha)$
- need $\mathcal{S}_{00}$ (TDCPV) for $B^0 \to \pi^0\pi^0$ to solve ambiguity.

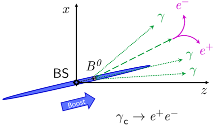
First attempt to measure $S_{\pi^0\pi^0}$

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

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

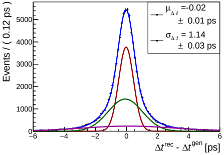


Pure Dalitz

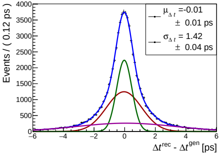


Converted

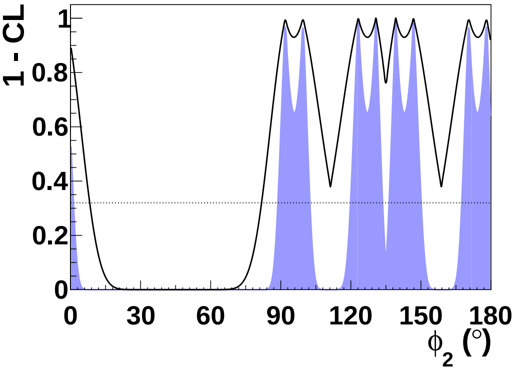
$\delta(\Delta t) = 1.14 \pm 0.03$ ps



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



Belle, Belle II (50 ab^{-1})

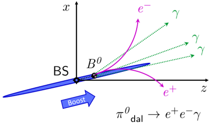


ϕ_2 measurement: $B \to \pi^0\pi^0$ sensitivity

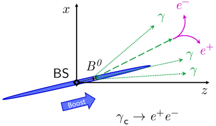
First attempt to measure $S_{\pi^0\pi^0}$

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

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



Pure Dalitz



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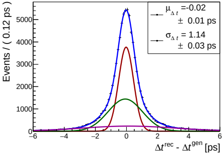

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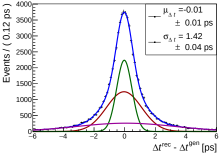
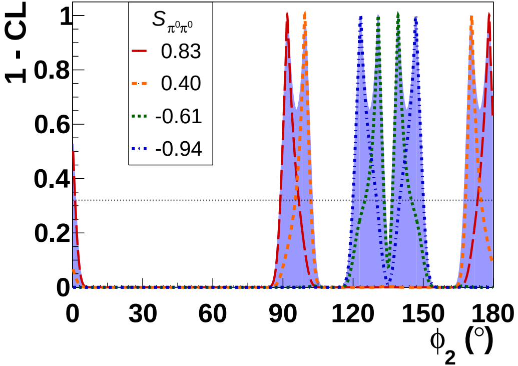
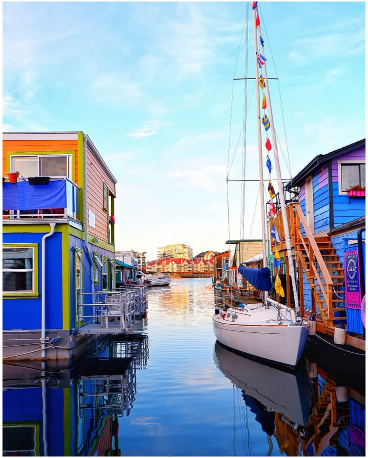


Belle, Belle II (50 ab^{-1}) (+ $S_{\pi^0\pi^0}$)



- different solution depending on the actual value of $S_{\pi^0\pi^0}$: 4 shown
- $\Delta\phi^{exp}_{2,\pi\pi}\big|^{88^\circ}_{1\sigma} \sim 2^\circ$ (Combined: $\sigma_{\phi_2}(\pi\pi, \rho\rho) \sim 0.6^\circ$)

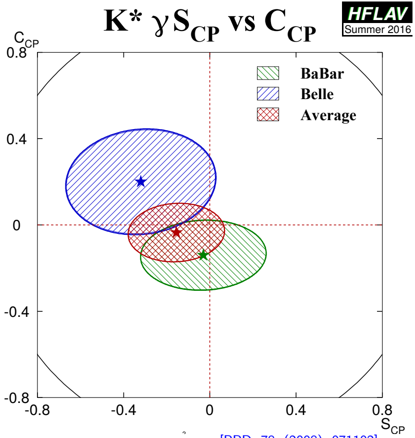
Outline



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.
- SM: $S^{SM}_{K^0_S\pi^0\gamma} \sim -2\frac{m_s}{m_b}\sin 2\phi_1 = -(2.3 \pm 1.6)\%$ [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

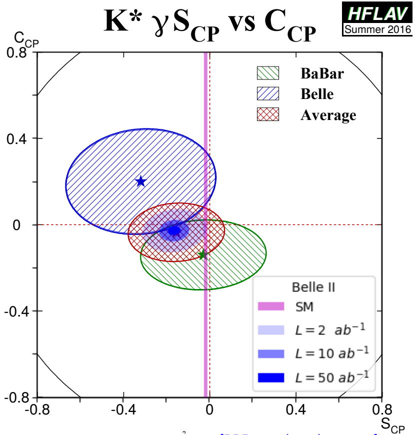


- BaBar ($N_{B\overline{B}} = 467 \cdot 10^6$) [PRD 78 (2008) 071102]
- Belle ($N_{B\overline{B}} = 535 \cdot 10^6$) [PRD 74 (2006) 111104(R)]

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

Motivation:

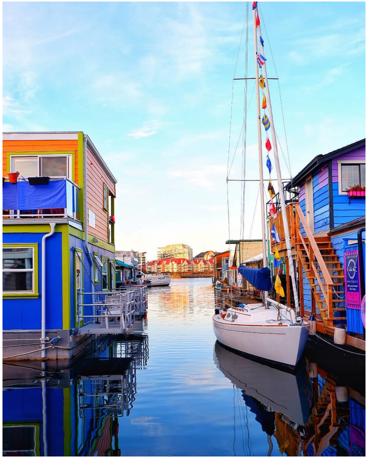
- $b \to s\gamma_R$ is helicity suppressed $(\frac{m_s}{m_b})$ wrt $b \to s\gamma_L$
- $B^0 \to f_{CP}\gamma_R$ interferes with $B^0 \to \overline{B}^0 \to f_{CP}\gamma_R$ only for helicity suppressed $b \to s\gamma_R$ decay
- TDCPV analysis is sensitive to the decay rate of b into "wrongly" polarized γ.
- SM: $S^{SM}_{K^0_S\pi^0\gamma} \sim -2\frac{m_s}{m_b}\sin 2\phi_1 = -(2.3 \pm 1.6)\%$ [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
- Interesting at Belle II already with few ab^{-1}
  - Very hard (if possible at all) at LHCb
  - also $B^0 \to K^0_S\pi^+\pi^-\gamma$ channel



- 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)]
- **Belle II: $L = 2, 10, 50\,\mathrm{ab}^{-1}$**

Outline

1. Introduction
   - CPV and CKM 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
   - $B \to \pi\pi$
5. New Physics with TDCPV
   - $B^0 \to K^0_S\pi^0\gamma$
6. **Conclusion and outlook**



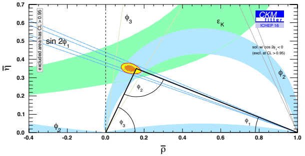
Conclusion and outlook

Belle II TDCPV program at SuperKEKB

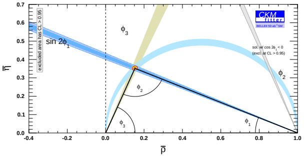
- large dataset with an improved detector and algorithms.
- unique possibilities for modes with final states with neutrals, complementary to LHCb
- CKM angles $\phi_{1,2}$ will be measured with TDCPV at 1% level;
  - ϕ_1 will remain the most precisely measured angle,
  - ϕ_2 will benefit from new input ($S_{\pi^0\pi^0}$) and reduced uncertainties;
- **possible timeline, looking at Belle/BaBar publications**
  - ✓ TDCPV $B^0 \to J/\psi K^0_S$ with $\sim 10/20\,\text{fb}^{-1}$ **this summer?**
  - $\mathcal{B}(\eta' K^0_S)$ with $10\,\text{fb}^{-1}$, TDCPV with $40\,\text{fb}^{-1}$
  - TDCPV ϕK^0_S with $140/50\,\text{fb}^{-1}$ **end of the year?**
  - TDCPV $B^0 \to \pi^+\pi^-$ with $40\,\text{fb}^{-1}$
  - ✗ $\mathcal{B}(B^0 \to \pi^0\pi^0)$ with $\sim 200\,\text{fb}^{-1}$, TDCPV with $\sim 50\,\text{ab}^{-1}$
  - ✗ **NP** Probe for NP in TDCPV $B^0 \to K^0_S\pi^0\gamma$ (few ab^{-1})
- More information in B2TIP report[hep-ph/1808.10567]

CPV only input

Current world average



Belle II projection @ 50ab^{-1}



Belle II

- large (
- unique
  compl
- CKM
  - ϕ_1
  - ϕ_2
- possib
  - ✓ TD
  - $\mathcal{B}(\eta$
  - TD
  - TD
  - ✗ $\mathcal{B}($E
  - ✗ NP
- More

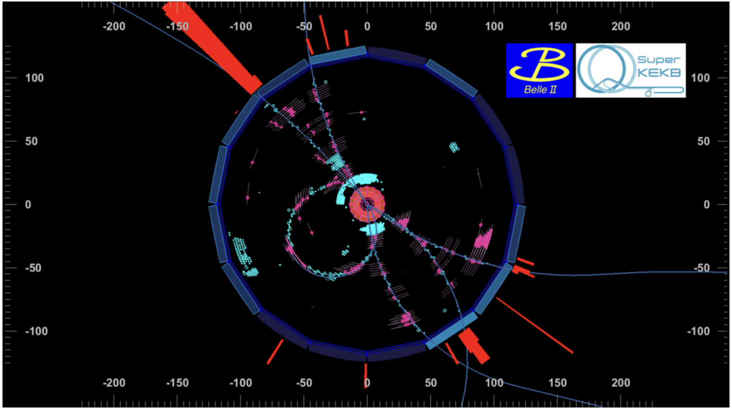
t

erage

50ab^{-1}

Second "First" SuperKEKB collision on March 11^{th}

Phase III - Full detector installed and operating

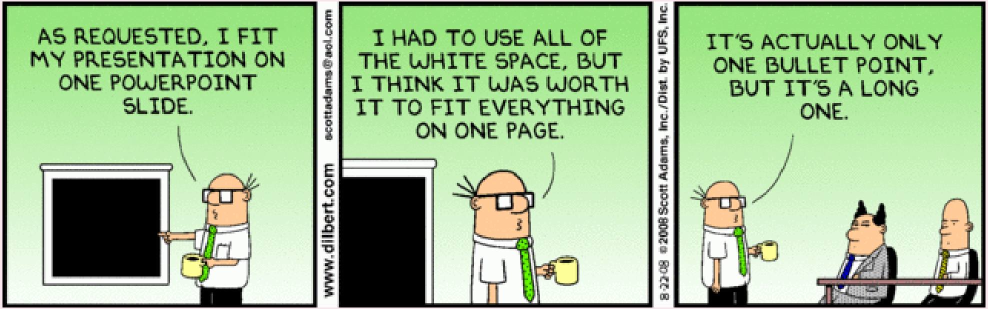


B-factories are back in the game

Other Belle II talks at FPCP

- 7/5 *Measurement of the CKM angle γ with Belle II*, **Niharika Rout**
- 7/5 *Early physics prospects for radiative and electroweak penguin decays at Belle II*, **Justin Tan**
- 7/5 *Prospects for τ lepton physics at Belle II*, **David Perez**
- 8/5 *Semileptonic and leptonic B decay results from early Belle II data*, **Markus Prim**
- 8/5 *B lifetime and $\overline{B}^0$ B^0 mixing results from early Belle II data*, **Jakub Kandra**
- 9/5 *Dark Sector Physics with Belle II*, **Chris Hearty**
- 9/5 *Exotic Quarkonium Physics Prospects at Belle II*, **Jake Bennett**
- 9/5 *Sensitivity to the X(3872) total width at the Belle II experiment*, **Hikari Hirata**
- 10/5 *Belle II and SuperKEKB status and progress*, **Hulya Atmacan**

Additional or backup slides



Introduction

CPV

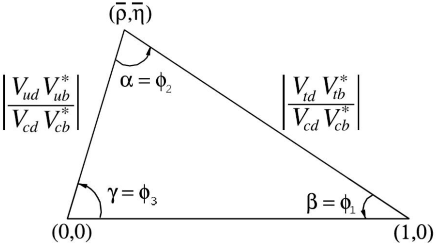
- Why CP-Violation?
  - Matter-Antimatter asymmetry in the universe.
  - Sakharov's 2^{nd} condition requires and CPV
  - current known CPV in SM way smaller than needed.
- B^0-system exhibits the largest CPV in the SM
- CPV in SM is due to weak interaction and it is described by V_{CKM} matrix ($\lambda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

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

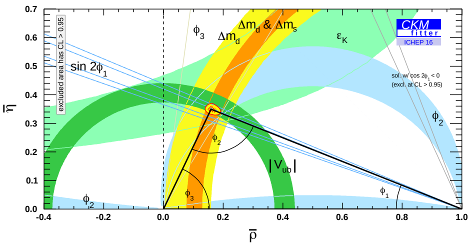
- Unitarity requires: $\Sigma_k V^*_{ki} V_{kj}$ so $V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0$
  - $\mathcal{O}(\lambda^3) + \mathcal{O}(\lambda^3) + \mathcal{O}(\lambda^3)$
- **main goal of Belle II is to precisely measure the CKM unitary triangle, and look for Beyond-SM physics using precision measurements at the intensity frontier.**

CP Violation in B meson systems

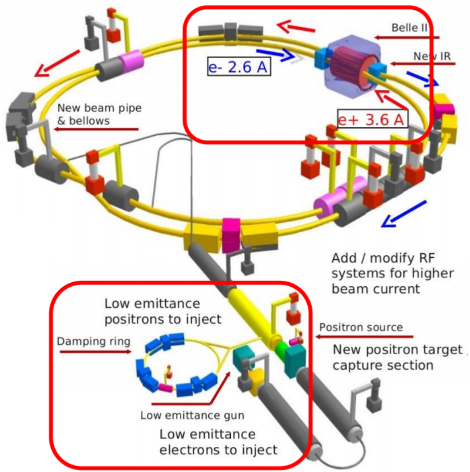
- Three angles ($\sim$ phases $\sim$ CPV) and three sides ($\sim$ Amplitudes $\sim$ BR):
  - $\phi_1 = \beta$: accessible via B^0 oscillation analysis $b \to c\bar{c}s$ and $b \to q\bar{q}s$
  - $\phi_2 = \alpha$: accessible via B^0 oscillation analysis $b \to u\bar{u}d$
  - $\phi_3 = \gamma$: relative phase of tree level bc and bu coupling;
- $\phi_{1,2}$ can be accessed via Time-Dependent $C\!\!\!/P$ Violation analysis of asymmetry in B^0 meson decay rate into CP eigenstate (TDCPV)

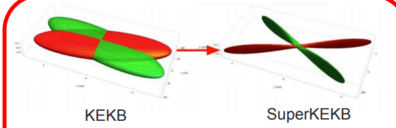


Current world average



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





"nano-beam" scheme
Beam squeezing: x20 smaller at IR

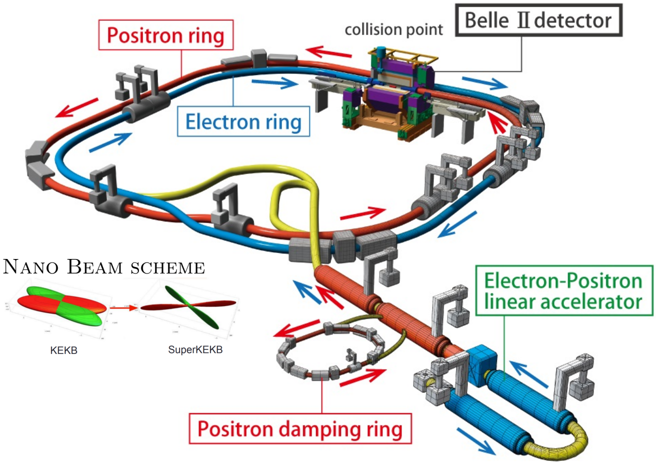
$$\text{Luminosity} = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\frac{R_L}{R_y}$$

x2 ($I_\pm$)

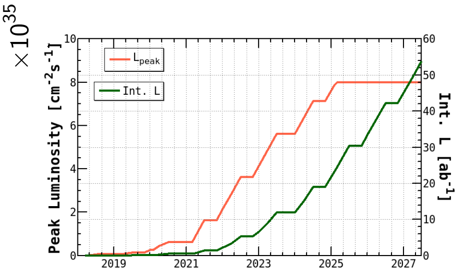
X1/20 (β_y^*)

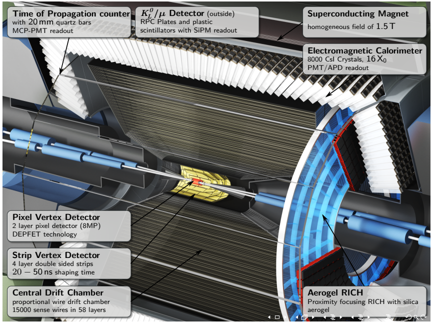
Target luminosity: $8\times10^{35}\,cm^{-2}s^{-1}$
KEKB x 40!

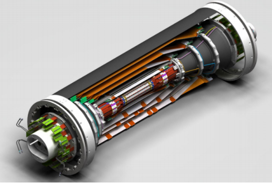
$e^- e^+$ asymmetric collider at $\sqrt{s}$ of $\Upsilon(4S)$



	KEKB	SuperKEKB
$\mathcal{L}$ $(10^{34}s^{-1}cm^{-2})$	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
$\langle \Delta z \rangle$ (μm)	$\sim$ 200	$\sim$ 130





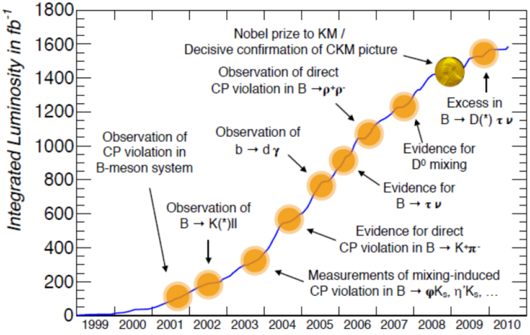


Major upgrade of Belle apparatus for all detectors

- **Challenges:**
  - higher background
  - reduced boost
- **Improvement** [Belle II TDR, arXiv:1011.0352]
  - New, extended **vertex** detector
    - ★ 1(+1[2020]) pixel layers: DEPFET technology
    - ★ 4 layers of double sided Si microstrip sensors
    - ★ Not present in **phase II** data taking (2018)
    - ★ fully installed for 2019 run **phase III**
  - **CDC**: smaller cell size and longer lever arm
    - ★ Better K_S^0 reconstruction
  - **ECL**: improved electronics and light yield
  - **TOP-ARICH** New Particle ID detector for K/π separation
  - Improved **KLM** (K_L^0, μ) electronics

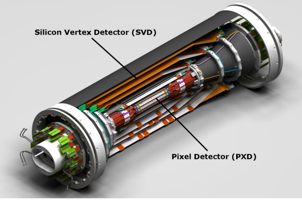
B-factories (BaBar @ SLAC and Belle @ KEKB): a 10 year long success:

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

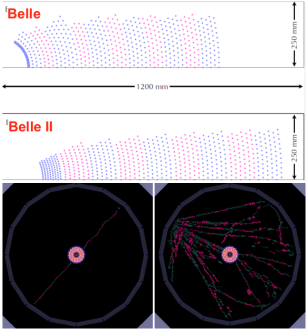


- Discovery of CPV in B-system, indirect and direct;
- confirmation of CKM description of flavour phys;
- precision measurement of CKM elements;
- obs of several new hadronic states
- strong evidence of D meson mixing

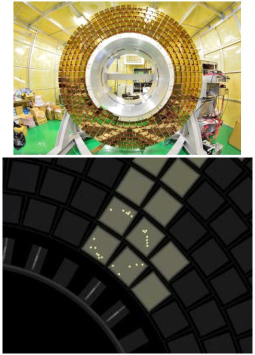
SVD and PXD



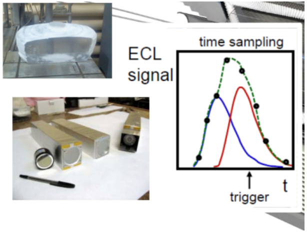
CDC



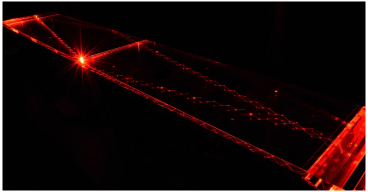
ARICH

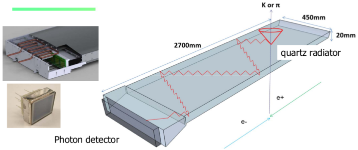


ECL

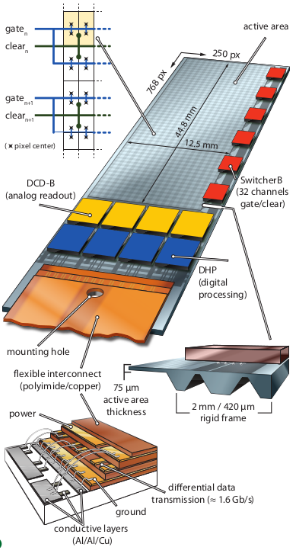


TOP





Pixel Detector



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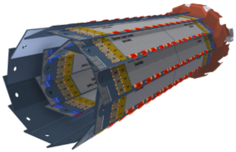
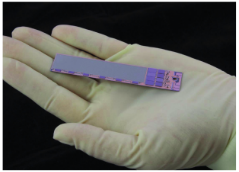




- Inst. Lumi.: $\mathcal{L}_{\text{Belle II}} \sim 40 \cdot \mathcal{L}_{\text{Belle}}$

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

- Closest to IP

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

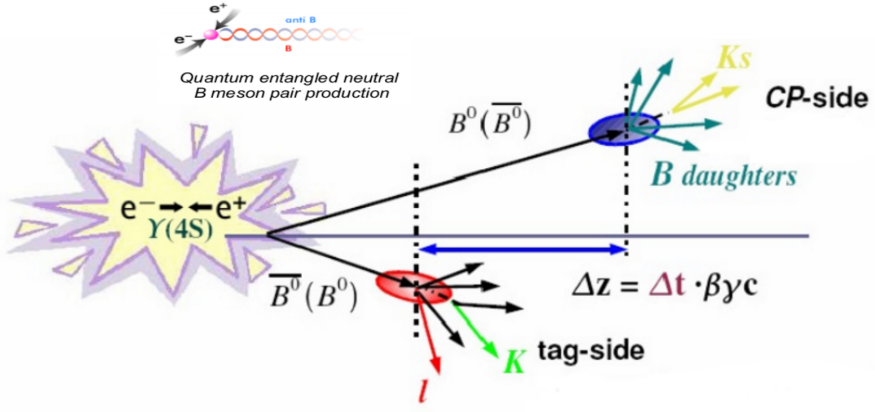
- $\langle\beta\gamma\rangle_{\text{Belle II}} < \langle\beta\gamma\rangle_{\text{Belle}}$

$\Rightarrow$ smaller Δz

$\Rightarrow$ Pixel Detector needed !

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

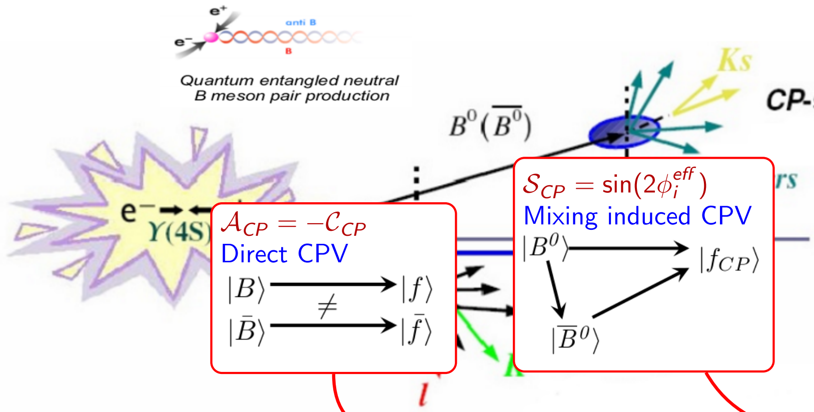
Time Dependent $\not{C}\not{P}$ Violation Measurements



Time Dep. $\not{C}\not{P}$: 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



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

Direct CPV

$|B\rangle \rightarrow |f\rangle$

$\neq$

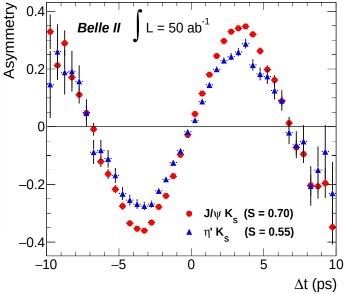
$|\bar{B}\rangle \rightarrow |\bar{f}\rangle$

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

Mixing induced CPV

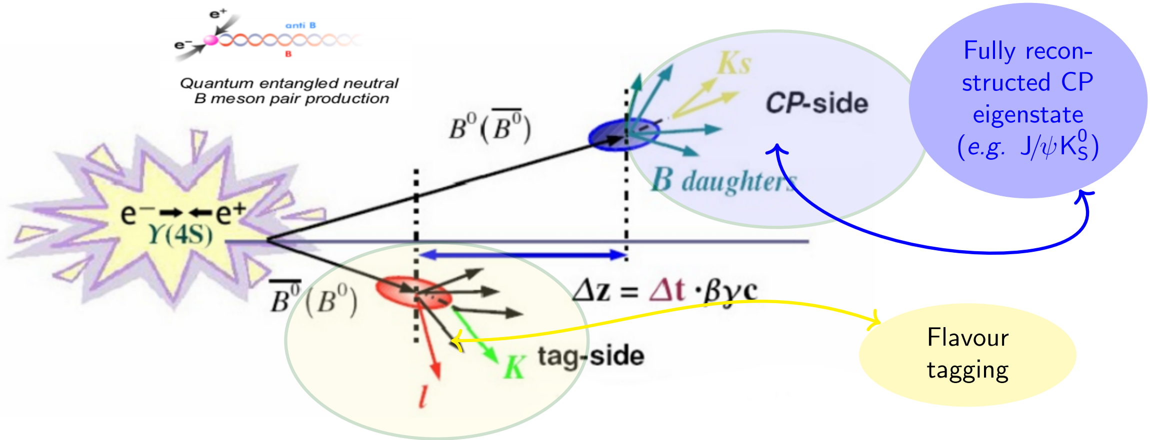
$|B^0\rangle \rightarrow |f_{CP}\rangle$, $|B^0\rangle \rightarrow |\overline{B}^0\rangle \rightarrow |f_{CP}\rangle$

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



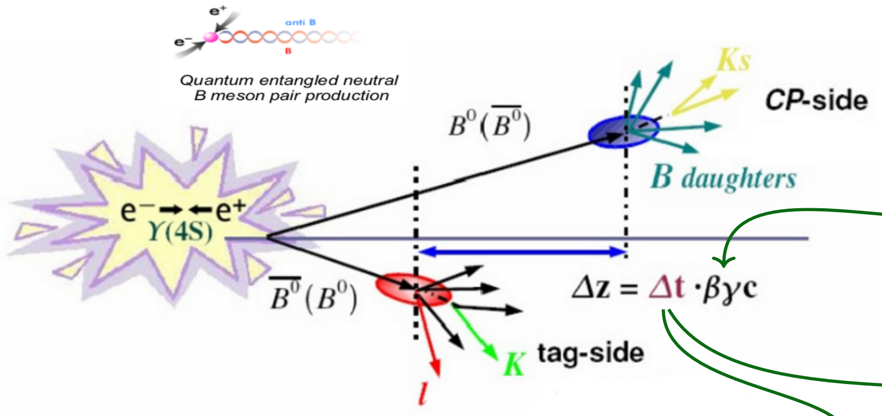
probabilty parametrization vs Δt : $\mathcal{P}(\Delta t, q) = \frac{e^{-\Delta t/\tau_{B^0}}}{4\tau_{B^0}} [1 + q(\mathcal{A}_{CP} \cos \Delta m_d \Delta t + \mathcal{S}_{CP} \sin \Delta m_d \Delta t)]$

Time Dependent CP Violation Measurements



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

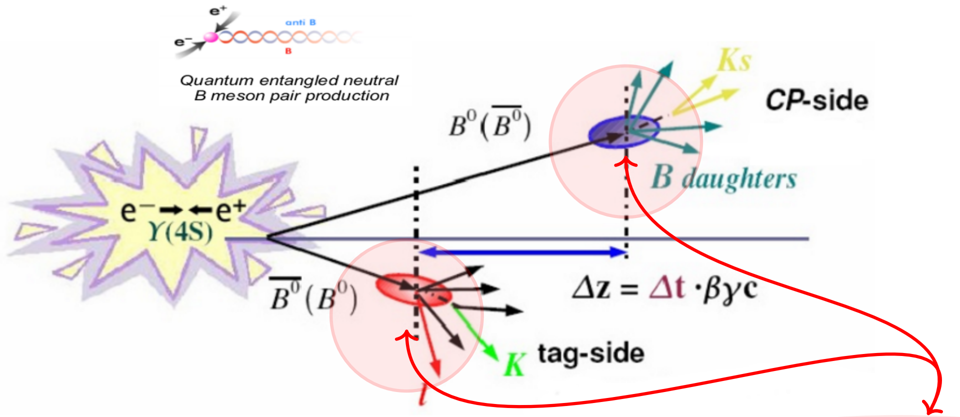
Time Dependent $\not{CP}$ Violation Measurements



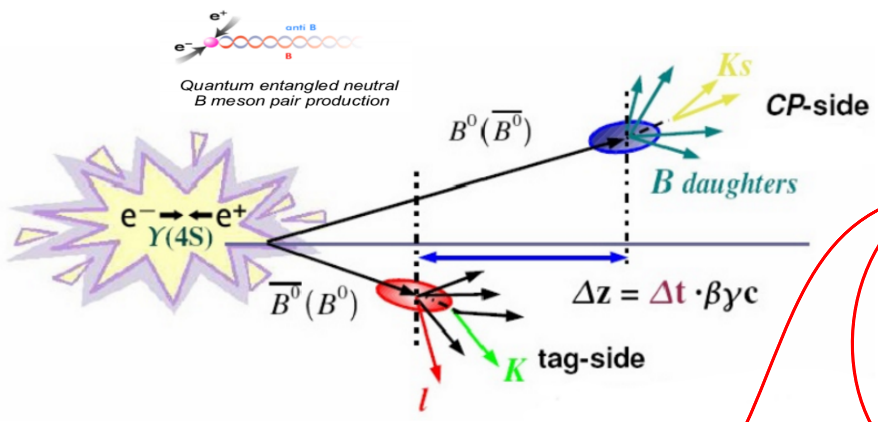
$\beta\gamma =$ **0.28** (0.45)
Belle2 (Belle)

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



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

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

$\sin(2\beta)$ 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

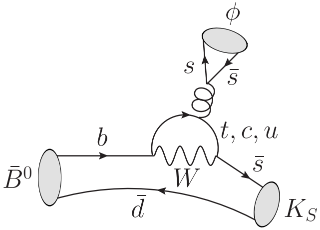
Expected yields and uncertainties on the S and A parameters for the channels sensitive to $\sin(2\phi_1)$ discussed in this chapter for an integrated luminosity of 50 (5) ab^{-1} for $J/\psi K^0$ (penguin dominated modes). In the 5th and the last column are shown the present WA errors on each of the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

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

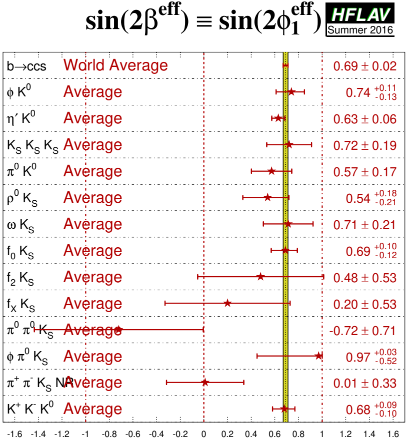


Motivations:

- 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



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

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 $\mathcal{B}_{\rho^0\rho^0} \ll \mathcal{B}_{\rho^+\rho^-}$

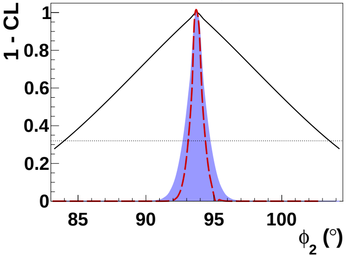
	Value	0.8 ab^{-1}	50 ab^{-1}
$f_{L,\rho^+\rho^-}$	0.988	$\pm0.012 \pm 0.023$ [1]	$\pm0.002 \pm 0.003$
$f_{L,\rho^0\rho^0}$	0.21	$\pm0.20 \pm 0.15$ [2]	$\pm0.03 \pm 0.02$
$\mathcal{B}_{\rho^+\rho^-}$ [10^{-6}]	28.3	$\pm1.5 \pm 1.5$ [1]	$\pm0.19 \pm 0.4$
$\mathcal{B}_{\rho^0\rho^0}$ [10^{-6}]	1.02	$\pm0.30 \pm 0.15$ [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)]

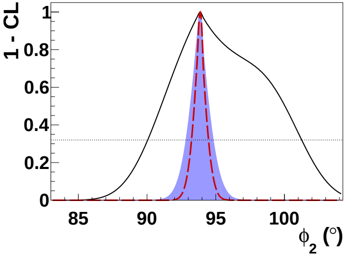
$\sigma^{\rho\rho}_{\phi_2} \sim 0.7^\circ$(WA $\pm 5^\circ$)

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

only $B \to \rho\rho$



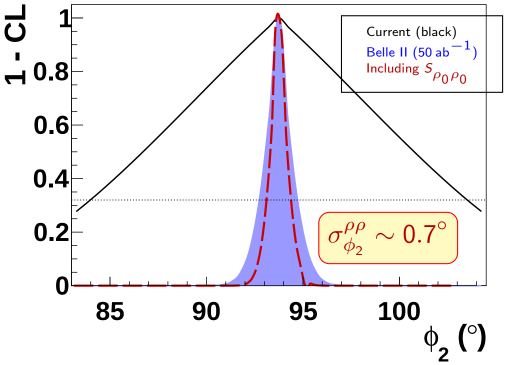
$B \to \pi\pi$ and $\rho\rho$



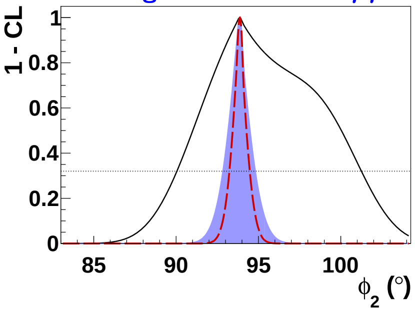
ϕ_2/α from $B^0 \to \rho\rho$ and combined $B^0 \to \pi\pi,\ \rho\rho$

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

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). $\sigma_{\phi_2} \sim 5^\circ$

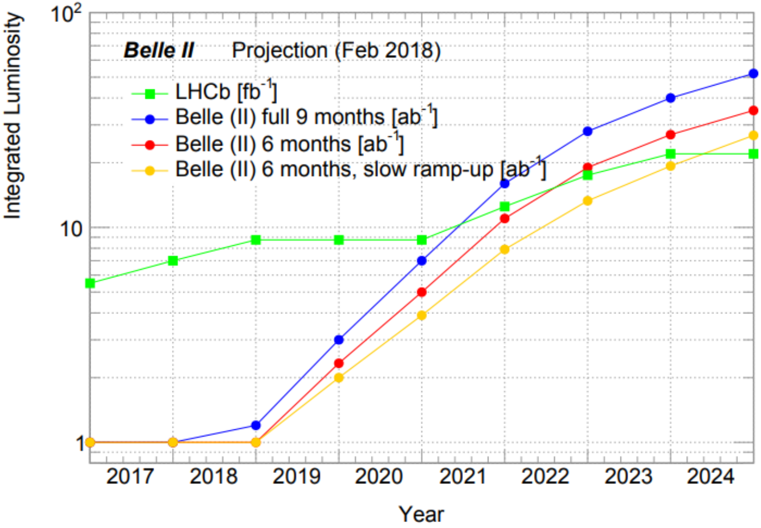
	Value	0.8 ab^{-1}	50 ab^{-1}
$f_{L,\rho^+\rho^-}$	0.988	$\pm 0.012 \pm 0.023$ [77]	$\pm 0.002 \pm 0.003$
$f_{L,\rho^0\rho^0}$	0.21	$\pm 0.20 \pm 0.15$ [83]	$\pm 0.03 \pm 0.02$
$\mathcal{B}_{\rho^+\rho^-}$ [10^{-6}]	28.3	$\pm 1.5 \pm 1.5$ [77]	$\pm 0.19 \pm 0.4$
$\mathcal{B}_{\rho^0\rho^0}$ [10^{-6}]	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} $\sigma_{\phi_2} \sim 2.5^\circ$

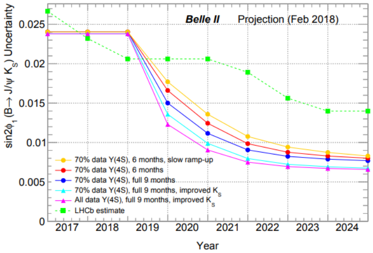
$B^0 \to \rho\pi$

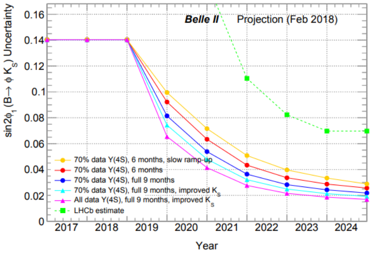
- Analysis done with Dalitz plot on $\pi^+\pi^-\pi^0$ final state.
- current analyses by BaBar and Belle suffer from low statistics
- which cause secondary solutions for ϕ_2 on both sides of primary
- and expected to vanish with larger dataset
- Strong motivation to repeat the analysis with at least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

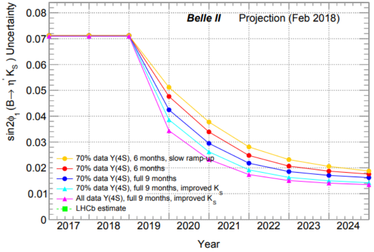
Competition with LHCb: luminosity



Competition with LHCb: ϕ_1



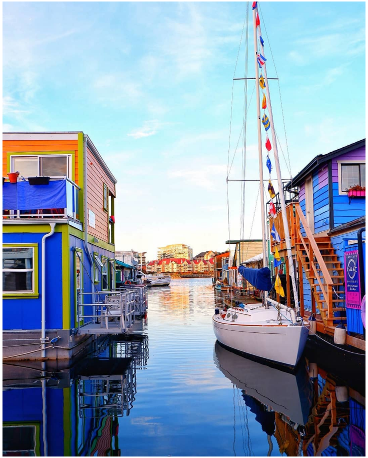




Outline

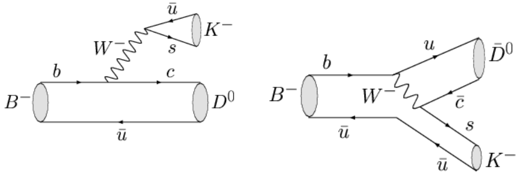
- $B \to \rho\rho$
- Unitary triangle
- $B \to \rho\rho$

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



ϕ_3/γ measurement

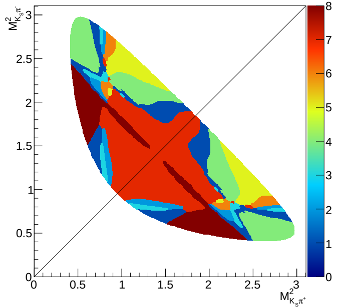
- ϕ_3/γ is the phase between $b \to c$ and $b \to u$
- from interference of tree-level diagrams
  - ✓ no B mixing, nor penguin pollution
    - ★ theoretical ambiguity very small
  - ✗ different strong phase
    - ★ today CLEO-c results [PRD82, 112006 (2010)]
    - ★ improvement from BESIII ($10\,\mathrm{fb}^{-1}$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



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

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

- Golden mode for Belle II ;
- large $\mathcal{B}$, 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)]



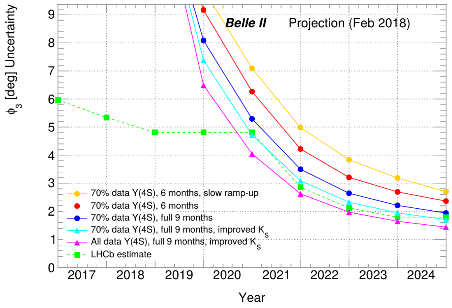
ϕ_3/γ sensitivity

Current status:

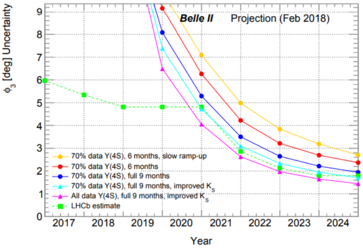
$$\phi_3^{Belle} = \left(78^{+15}_{-16}\right)^\circ \quad \phi_3^{LHCb} = \left(76.8^{+5.1}_{-5.7}\right)^\circ$$

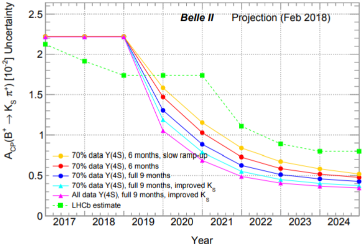
- sensitivity study on GGSZ $B^\pm \to D[\to K^0_S\pi\mu]K^\pm$
  - expected sensitivity to $\phi_3 \sim 3^\circ$ with $50\,ab^{-1}$
- improvement including:
  - **GGSZ** $D \to K^0_S K^+ K^-$ and $B^\pm \to D^* K^\pm$
  - **ADS/GLW** modes $B^\pm \to D^*[\to D\gamma\pi^0]K^\pm$
- LHCb will dominate 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** $K^0_L\pi^+\pi^-$, $K^0_L K^+ K^-$, $K^0_S\pi^+\pi^-\pi^0$, $\pi^+\pi^-\pi^0\pi^0$.

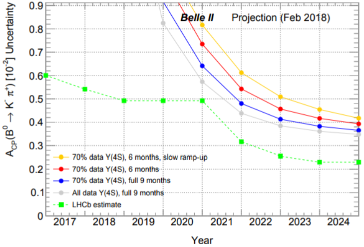
Projected ϕ_3 sensitivity for different luminosity profile scenarios



Competition with LHCb: ϕ_3







Competition with LHCb: Direct CPV