Time Dependent CP violation perpectives for BelleII

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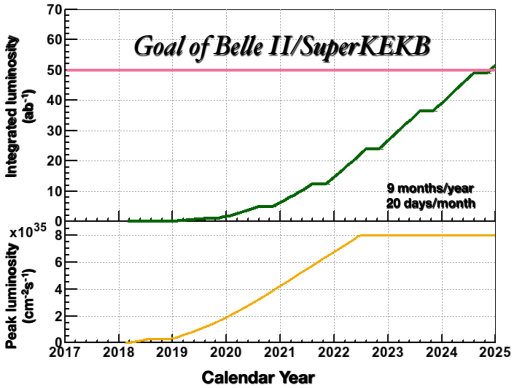
INFN Padova

JENNIFER Consortium General Meeting,
KEK, 6 October 2017,

Introduction

Will present Time Dependent CP violation analysis in BelleII



- Perspective at BelleII within the scope of Jennifer II (2018-2023)
- $\int \mathcal{L} dt = 5 - 10\,\mathrm{ab}^{-1}$;
- Probably more L (up to $25\,\mathrm{ab}^{-1}$), but need time to finalize analysis.

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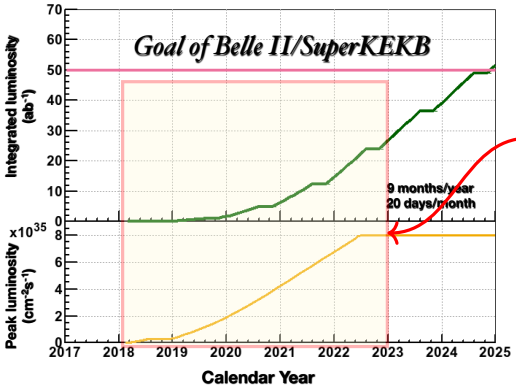
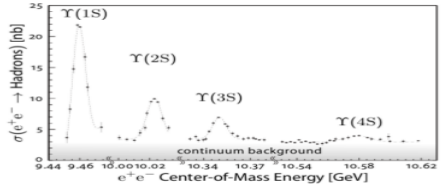


- Perspective at BelleII within the scope of Jennifer II (2018-2023)
- $\int \mathcal{L} dt = 5 - 10\,\mathrm{ab}^{-1}$;
- Probably more L (up to $25\,\mathrm{ab}^{-1}$), but need time to finalize analysis.

- Very little or no technical details;
- Only physics motivation, estimated reach;
- and possible competition with LHCb

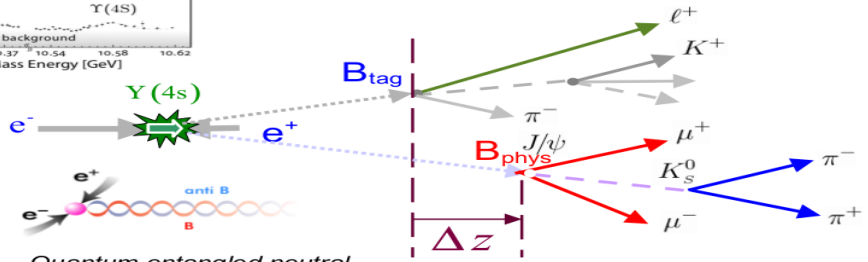
Time Dependent CP violation in a nutshell



- Υ(4S) is the first resonance just above the $B\bar{B}$ production threshold
- Only $B\bar{B}$ pairs are produced, and are at rest in the Υ(4S) frame

$$\Delta t = \frac{\Delta z}{\beta \gamma c}$$

Resolution on Δt will be dominated by the resolution of the tagging side vertex



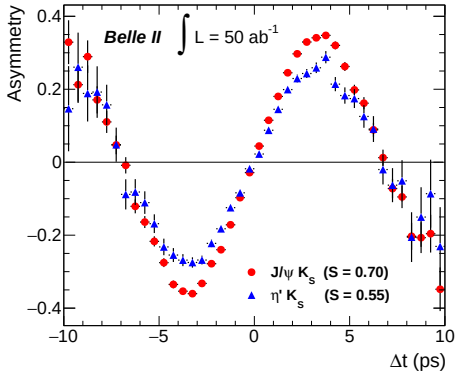
Quantum entangled neutral B meson pair production

Belle ~ 200 μm
Belle II ~ 130 μm

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

Motivations

$$Asym = \frac{\mathcal{P}(B^0 \to X_{CP}) - \mathcal{P}(\bar{B}^0 \to X_{CP})}{\mathcal{P}(B^0) + \mathcal{P}(\bar{B}^0)} = \mathcal{A}\cos(\Delta m \Delta t) + \mathcal{C}\sin(\Delta m \Delta t)$$



Needs everything!

- exclusive B^0 signal reconstruction;
  - charged and neutral particles
  - PID
  - vertexing
- Flavour tagging of ${B^0}_{tag}$;
- Measure Δz

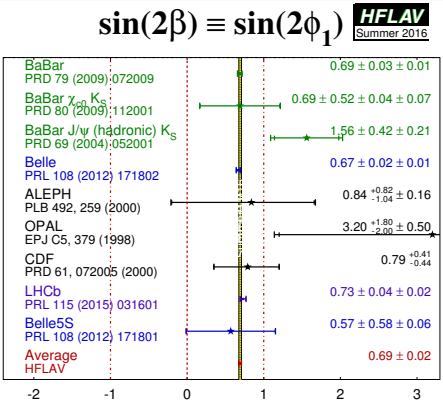
Physics motivation

- determination of $\phi_1(\beta)$
- measurement of $\phi_2(\alpha)$
- sensitiveness to New Physics

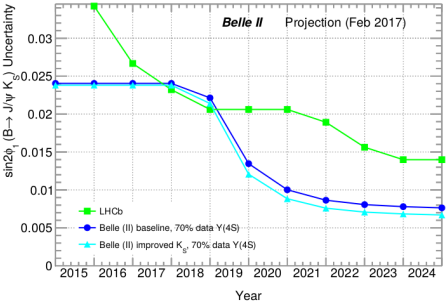
$b \to c\bar{c}s$: $B^0 \to J/\psi K^0_S$

From $\mathcal{A}$ direct access to $\sin(2\phi_1)$
(small penguin pollution)
Most precise determination of ϕ_1 today

Current status
$\mathcal{S} = 0.667 \pm 0.023 \pm 0.012$ (stat lim)
$\mathcal{C} = -0.006 \pm 0.016 \pm 0.012$



Competition from LHCb:



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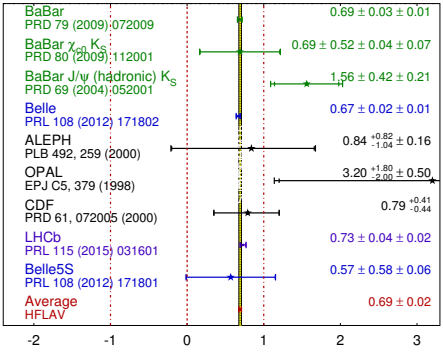
$\sin(2\beta) \equiv \sin(2\phi_1)$ HFLAV Summer 2016



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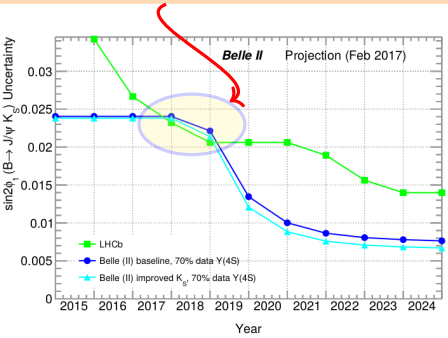


$b \to c\bar{c}s$: $B^0 \to J/\psi K^0_S$ extrapolation

$$\sigma^{\sin 2\beta}_{\text{total}} = \sqrt{(0.023^2 + 0.010^2) \times 0.711/\mathcal{L}_{\text{int}} + 0.007^2}$$

	Statistical	Systematic (reducible, irreducible)	Total
$\sin 2\beta$			
711 fb^{-1}	0.023	(0.010, 0.007)	0.026
5 ab^{-1}	0.009	(0.004, 0.007)	0.012
50 ab^{-1}	0.003	(0.001, 0.007)	0.008
$\mathcal{A}$			
711 fb^{-1}	0.016	(0.010, 0.011)	0.022
5 ab^{-1}	0.006	(0.004, 0.011)	0.013
50 ab^{-1}	0.002	(0.001, 0.011)	0.011

Belle measurement statistical error

Belle measurement reducible systematic error

Belle measurement non reducible systematic error

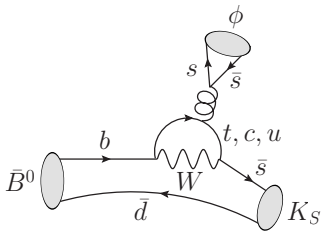
Integrated luminosity used in Belle measurement

Belle II expected integrated luminosity

With 5 fb^{-1} the stat and syst uncertainties on $\mathcal{S}$ will be comparable.
There will be strong competition with LHCb: this is a measurement that BelleII will do.
Other $b \to c\bar{c}s$ analysis $B^0 \to J/\psi\pi^0$, $B^0 \to D^{(*)}D^{(*)}$ not as competitive for ϕ_1

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

Gluonic penguin dominates.

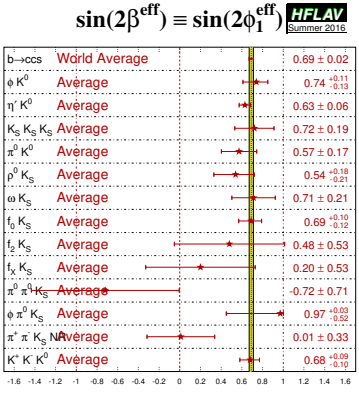


Motivations:

- probes ϕ_1 through different vertices
- more sensitive to new physics in the loop
- penguin pollution larger but different predictions available

Current status:

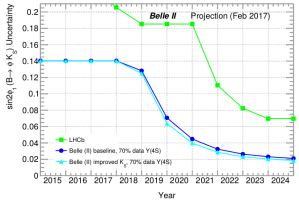
All measurement are statistically limited



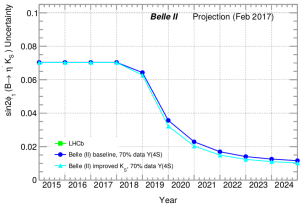
$b \to q\bar{q}s$: $B^0 \to \phi K^0_S$, $\eta' K^0_S$

competition with LHCb

only for ϕK^0_S



not for $\eta' K^0_S$



ϕK^0_S via Dalitz analysis of $K^+K^-K^0$ will be slow

Quasi-two body analysis:

- ϕK^0_S:
  - current $\sigma_S = 0.12$, $\sigma_C = 0.14$ (stat dominated, Belle+BaBar): fast improvement with L.

  $1\,ab^{-1}$ $\sigma_S = 0.11$, $\sigma_C = 0.08$

  $5\,ab^{-1}$ $\sigma_S = 0.048$, $\sigma_C = 0.035$
  - stat dominated up to $50\,ab^{-1}$
- $\eta' K^0_S$:
  - current $\sigma_S = 0.06$, $\sigma_C = 0.04$ (stat dominated, Belle+BaBar)

  $1\,ab^{-1}$ $\sigma_S = 0.06$, $\sigma_C = 0.04$

  $5\,ab^{-1}$ $\sigma_S = 0.027$, $\sigma_C = 0.020$
  - $(\sigma_{stat} \sim \sigma_{syst})$ around $\sim 10\,ab^{-1}$

$b \to q\bar{q}s$: ωK^0_S, $\pi^0 K^0_S$

- ωK^0_S State very similar to η'
  - $(\omega \to \pi^0\pi^+\pi^-)$
- extrapolation from Belle/BaBar results using η' full exercise
- current: $\sigma_S = 0.21$, $\sigma_C = 0.14$
- no LHCb competition

$1\,\text{ab}^{-1}$ $\sigma_S = 0.17$, $\sigma_C = 0.14$

$5\,\text{ab}^{-1}$ $\sigma_S = 0.08$, $\sigma_C = 0.06$

- $\pi^0 K^0_S$: state similar to $B^0 \to K^0_S \pi^0 \gamma$
- efficiency and Δt resolution from that channel
- current: $\sigma_S = 0.17$, $\sigma_C = 0.10$
- no LHCb competition

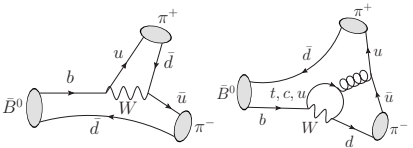
$1\,\text{ab}^{-1}$ $\sigma_S = 0.20$, $\sigma_C = 0.13$

$5\,\text{ab}^{-1}$ $\sigma_S = 0.09$, $\sigma_C = 0.06$

All these TDCPV measurements for ϕ_1: $B^0 \to (J/\psi, \phi, \eta', \omega, \pi^0)K^0$ can be done with $5 - 10\,\text{ab}^{-1}$ at BelleII

$\phi_2(\alpha)$ from $B^0 \to \pi\pi$

Isospin analysis: two amplitudes of comparable size with different weak phase:

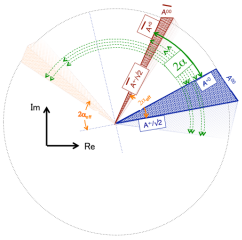


Estimate penguin contribution exploiting isospin relation among $A^{(i,j)} \equiv \mathcal{A}(B^{i+j} \to h^i h^j)$ $(h = \pi, \rho \ / \ i, j = \pm, 0)$

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

- need to measure all modes:
  - $\pi^+\pi^-$, $\pi^+\pi^0$, $\pi^0\pi^0$

Gronau-London method [PRL 64 3381 (1990)]



Picture from [arXiv:1705.02981]

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

- measuring rates construct the two triangles
- measuring asymmetries fix relative position
- triangles can flip: 8-fold ambiguity in $\phi_2(\alpha)$
- measuring TDCPV $B^0 \to \pi^0\pi^0$ solve ambiguity.

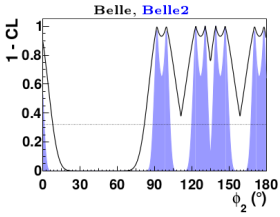
$\phi_2(\alpha)$ from $B^0 \to \pi^0\pi^0$

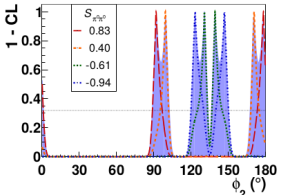
Isospin analysis input in $B \to \pi\pi$

	Value	Belle @ 0.8 ab^{-1}	Belle2 @ 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
[2]: PRD 88(9) 092003

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





$\Delta\alpha^{exp}_{\pi\pi}|^{88^\circ}_{1\sigma} \sim 4^\circ$

Time Integrated analisis ($B_{\pi^0\pi^0}, C_{\pi^0\pi^0}$) yield: 300 ev/ ab^{-1} ok at 5 ab^{-1} (BaBar used 250 ev)
But error on ϕ_2 scales approx as error on all 6 variables...
Time Dependent analisis ($S_{\pi^0\pi^0}$) yield: 300 ev at 50 ab^{-1}.

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

Similar to $B^0 \to \pi\pi$: 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

$b \to s\gamma$: $B^0 \to K^0_S \pi^0 \gamma$

Motivation:

- $b \to s\gamma_R$ is helicity suppressed wrt $b \to s\gamma_L$
- $B^0 \to f_{CP}\gamma_R$ interferes with $B^0 \to \overline{B}^0 \to f_{CP}\gamma_L$ only for helicity suppressed $b \to s\gamma_R$ decay
- TDCPV analysis is sensitive to the decay rate of b into "wrongly" polarized γ.
- New physics can enhance that decay rate

- Current status:

BaBar $S_{K^0_S\pi^0\gamma} = -0.78 \pm 0.59 \pm 0.09$,
$A_{K^0_S\pi^0\gamma} = 0.36 \pm 0.33 \pm 0.04$

Belle $S_{K^0_S\pi^0\gamma} = -0.10 \pm 0.31 \pm 0.07$,
$A_{K^0_S\pi^0\gamma} = -0.20 \pm 0.20 \pm 0.06$

- Neutral final state, low chances for LHCb;

Int. Lum. ab^{-1}	Stat(S)	Stat(A)
2	0.15	0.10
10	0.07	0.05
50	0.031	0.021

Interesting with few ab^{-1}

Summary

Channel	WA (2017) $\sigma(S)$	WA (2017) $\sigma(A)$	5 ab^{-1} $\sigma(S)$	5 ab^{-1} $\sigma(A)$	50 ab^{-1} $\sigma(S)$	50 ab^{-1} $\sigma(A)$
$J/\psi K^0$	0.022	0.021	0.012	0.011	0.0052	0.0090
ϕK^0	0.12	0.14	0.048	0.035	0.020	0.011
$\eta' K^0$	0.06	0.04	0.032	0.020	0.015	0.008
ωK^0_S	0.21	0.14	0.08	0.06	0.024	0.020
$K^0_S\pi^0\gamma$	0.20	0.12	0.10	0.07	0.031	0.021
$K^0_S\pi^0$	0.17	0.10	0.09	0.06	0.028	0.018

Observables	Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\sin 2\phi_1 (B \to J/\psi K^0)$	$0.667 \pm 0.023 \pm 0.012$	–	0.005
$S(B \to \phi K^0)$	$0.90^{+0.09}_{-0.19}$	0.068	–
$S(B \to \eta' K^0)$	$0.68 \pm 0.07 \pm 0.03$	0.027	–
$S(B \to J/\psi \pi^0)$	$-0.65 \pm 0.21 \pm 0.05$	–	0.10
ϕ_2 [°]	85 ± 4 (Belle+BaBar)	2	1
$S(B \to \pi^+\pi^-)$	$-0.64 \pm 0.08 \pm 0.03$	–	0.05
$Br.(B \to \pi^0\pi^0)$	$(5.04 \pm 0.21 \pm 0.18) \times 10^{-6}$	–	0.06
$S(B \to K^0_S\pi^0\gamma)$	$-0.10 \pm 0.31 \pm 0.07$	0.11	0.035

- A number of different analysis can be performed within the JenniferII timescope
- Many $b \to qqs$ are now statistically limited, so an update with increased stat is meaningful
- isospin analysis can be interesting as well
- For several a full scale exercise with BelleII tools have been performed.

Process	Observable	Theory	Syst. limit (Discovery) [ab^{-1}]	vs LHCb	vs Belle	Anomaly	NP
$B \to J/\psi K_S$	ϕ_1	⋆⋆⋆	5-10	⋆⋆	⋆⋆	⋆	⋆
$B \to \phi K_S$	ϕ_1	⋆⋆	>50	⋆⋆	⋆⋆⋆	⋆	⋆⋆⋆
$B \to \eta' K_S$	ϕ_1	⋆⋆	>50	⋆⋆	⋆⋆⋆	⋆	⋆⋆⋆
$B \to J/\psi\pi^0$	ϕ_1	⋆⋆⋆	>50	⋆	⋆⋆⋆		
$B \to \rho^\pm\rho^0$	ϕ_2	⋆⋆⋆		⋆	⋆⋆⋆	⋆	⋆
$B \to \pi^0\pi^0$	ϕ_2	⋆⋆	>50	⋆⋆⋆	⋆⋆⋆	⋆⋆	⋆⋆
$B \to \pi^0 K_S$	S_{CP}	⋆⋆	>50	⋆⋆⋆	⋆⋆⋆	⋆⋆	⋆⋆

Additional stuff

Additional or backup slides

Bibliography I