Belle II prospects for CP-violation measurements

Chiara La Licata for the Belle II Collaboration

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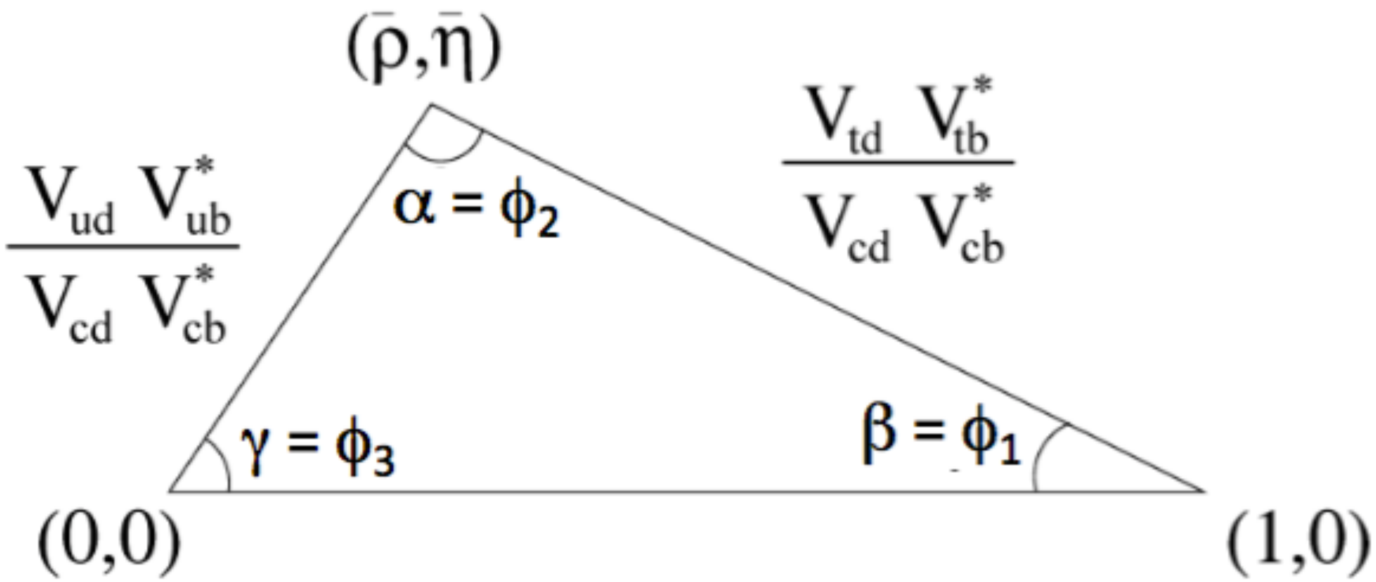
The Unitarity Triangle

- Quark interactions described by the V_{CKM} unitary matrix
- Unitarity relations represented by triangles in complex plane

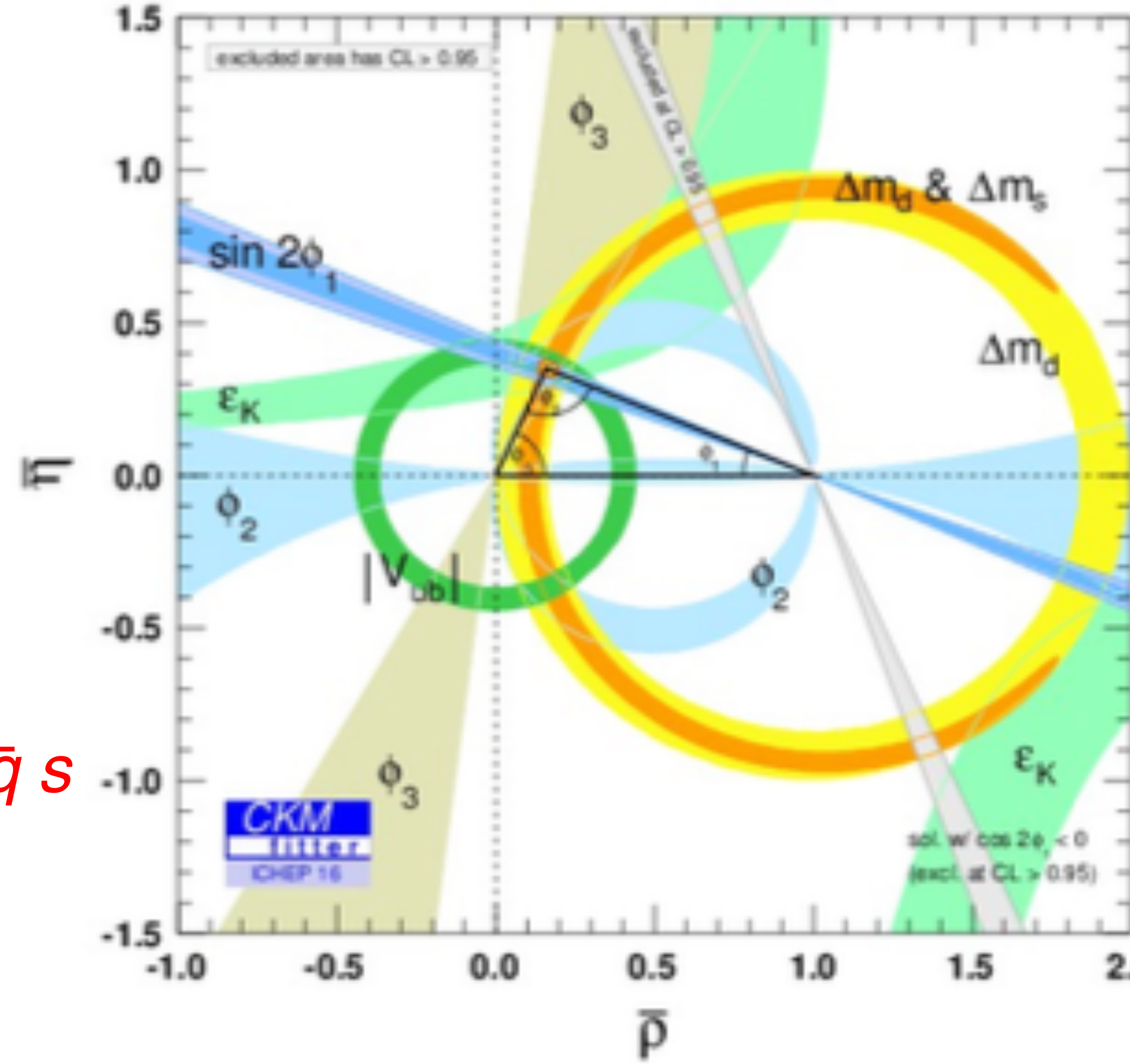
$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

$B \rightarrow u\,\bar{u}\,d$



$B \rightarrow c\,\bar{u}\,s$ $B \rightarrow c\,\bar{c}\,s$ $B \rightarrow q\,\bar{q}\,s$

current status



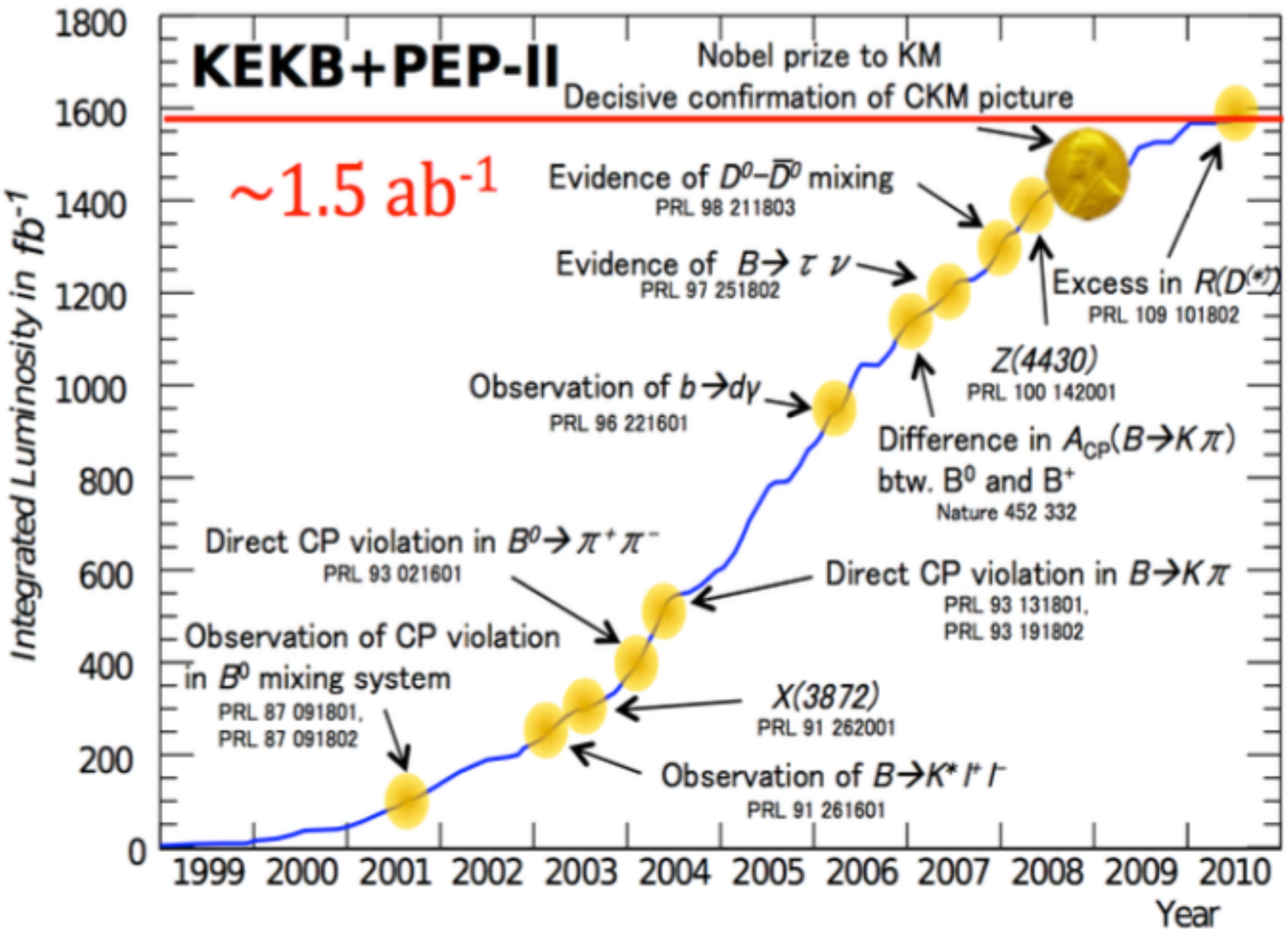
The presence of CP violation in the CKM matrix implies non-trivial values for these angles

Belle II goal → test the SM and search for non SM physics using precision measurements at the intensity frontier through measurements of the triangle parameters

Achievements at B factories

10 successful years:

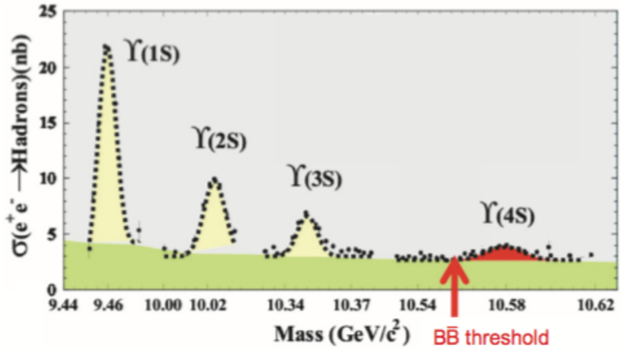
first generation of asymmetric B factories BaBar and Belle collected about 1.5 ab^{-1} of data during 1999 – 2010 → significant contribution to the understanding of the flavour dynamics in the Standard Model



- Discovery of CP violation in B meson transitions and confirmation of the CKM description of flavour physics
- Precision measurement of the CKM matrix elements and the angles of the unitarity triangle
- Constraints on various new physics models
- Observation of several new hadronic states
- Strong evidence of D meson mixing

Next generation B factory

SuperKEKB – major upgrade of the KEKB B factory at KEK

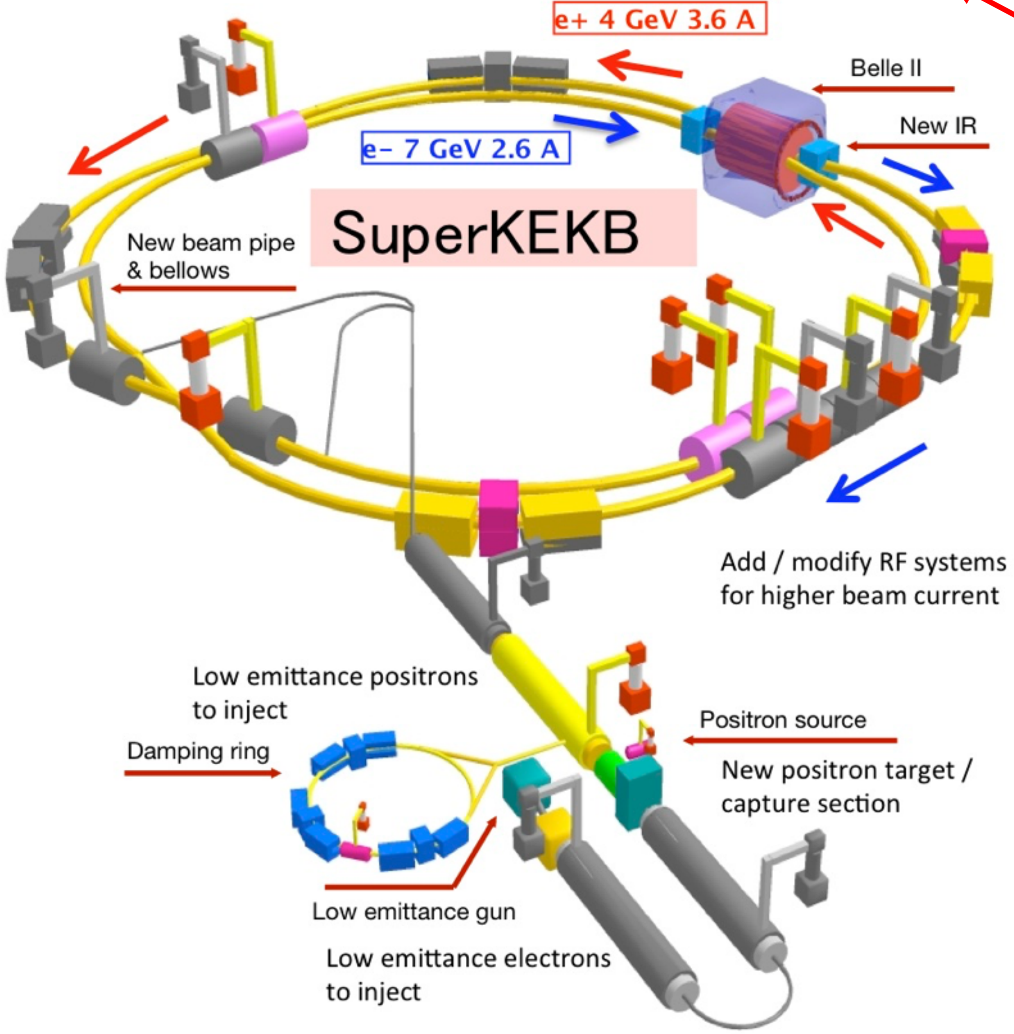


$e^+e^- \to$ BB mainly at $\sqrt{s}_{cm}$=10.58 GeV (Y(4S) resonance)

e^- 7GeV

x

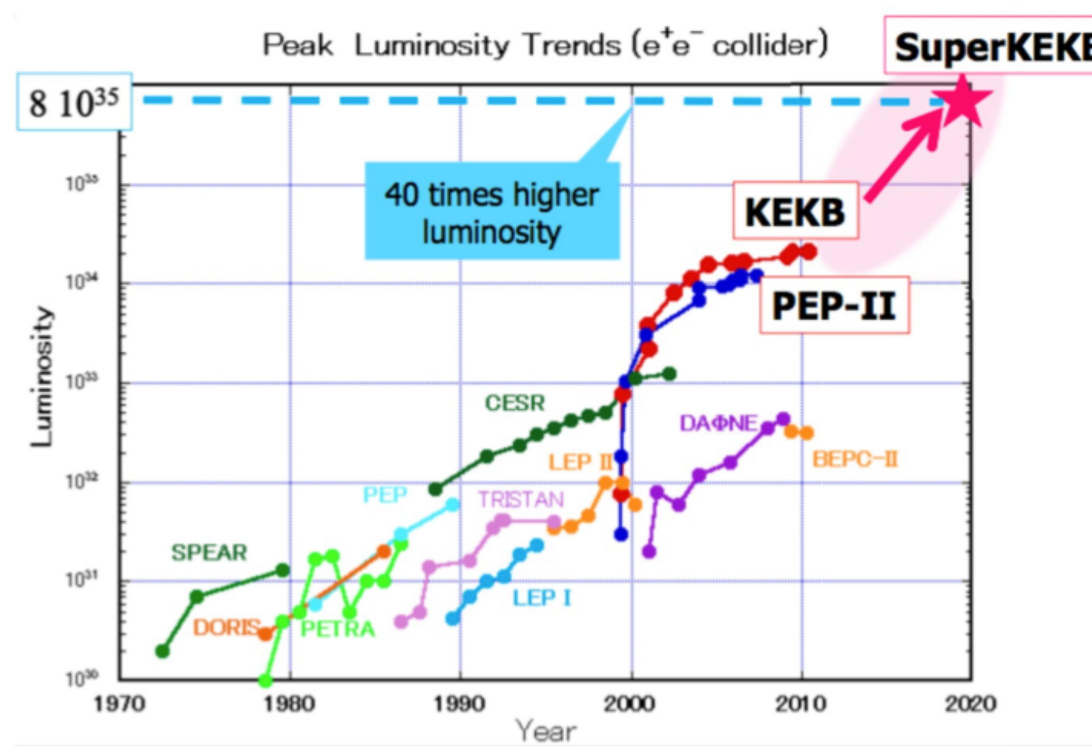
e^+ 4GeV



- Doubled beam currents
- Reduced beam spot size (nano beam scheme)

L_{peak}: 8x10^{35} cm^{-2}s^{-1} (40 x KEKB)

L_{int}: 50ab^{-1} by 2025 (50 x KEKB)



From Belle to Belle 2

Many upgrades to increase the performance and cope with more severe background conditions

Vertex Detector

- 2 pixel layers
- 4 layers of double-sided silicon microstrip sensors
  →Extended region

Central drift chamber

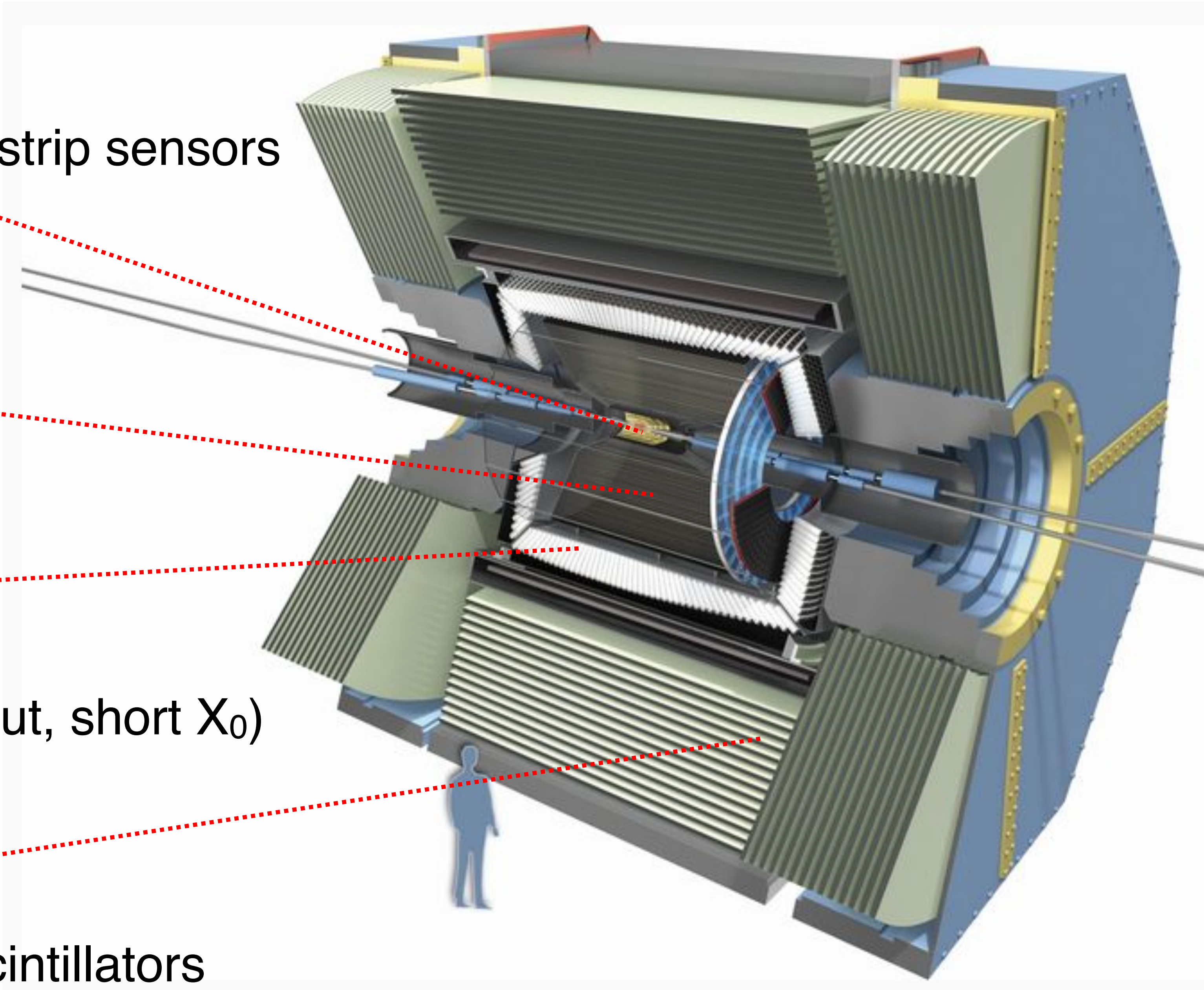
- Small cell size, longer lever arm

EM calorimeter

- upgrade of electronics
- CsI + CsI(Tl) crystals (high light output, short X_0)

K_L and muon detector

-some RPCs layers substituted with scintillators



From Belle to Belle 2

Many upgrades to increase the performance and cope with much more severe background conditions

Vertex Detector

- 2 pixel layers
- 4 layers of Si double side

→Extended VXD region

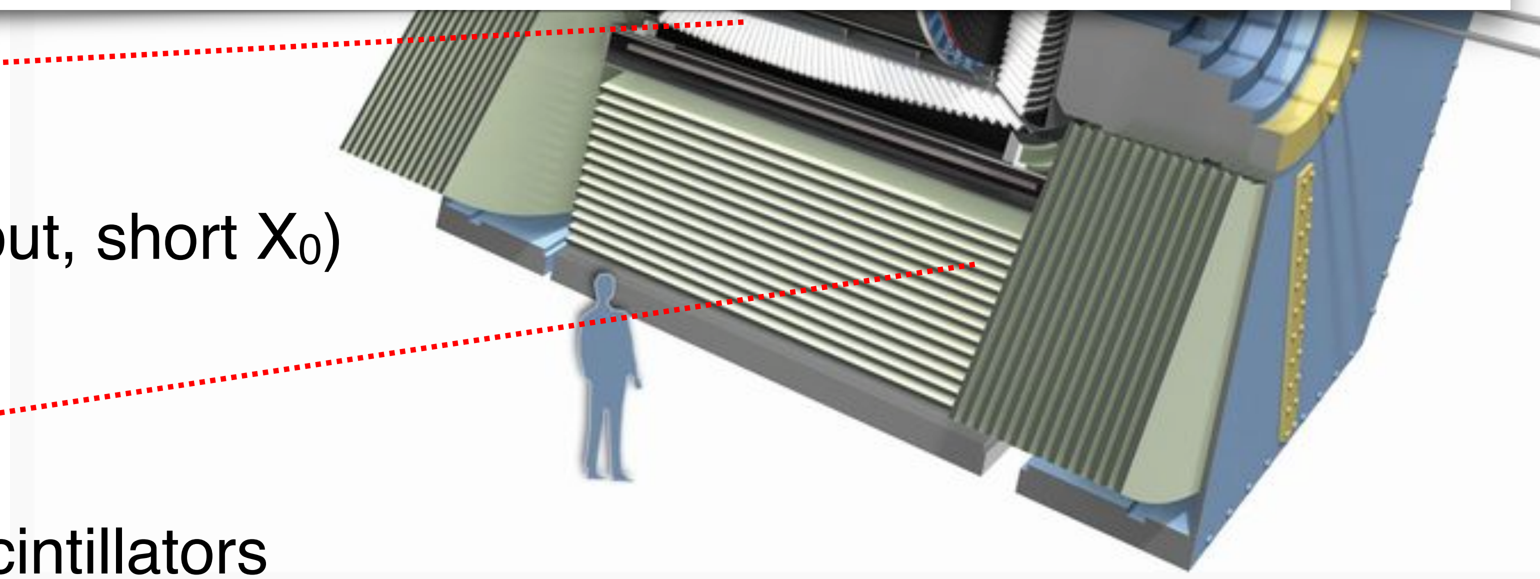
Central drift chamber

- Small cell size, longer le

- gain in robustness against beam-related background
- improvement in impact parameter resolution
- 30% increase Ks efficiency
- improved K/π separation with π fake rate decreases by ~2.5
- improved π^0 reconstruction

EM calorimeter

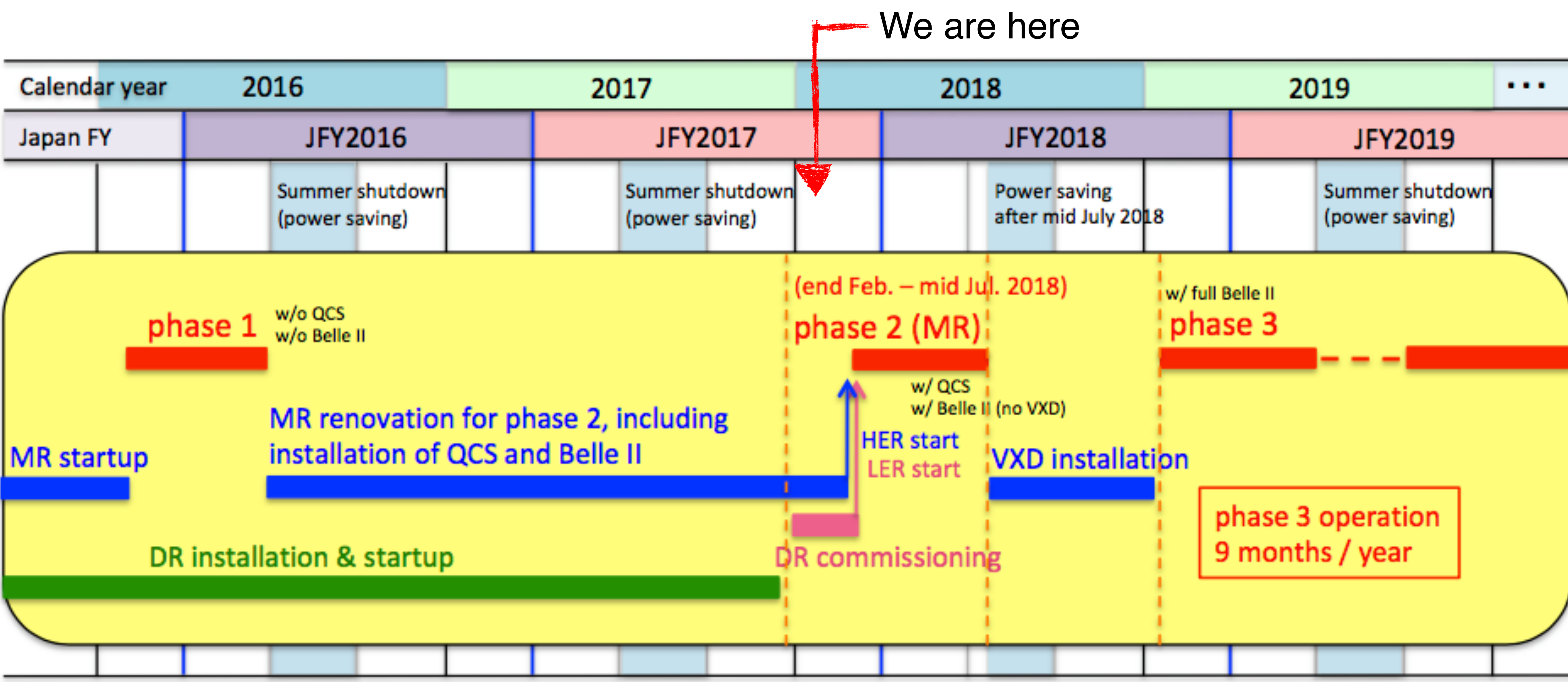
- upgrade of electronics
- CsI + CsI(Tl) crystals (high light output, short X_0)



K_L and muon detector

-some RPCs layers substituted with scintillators

Timeline



Phase 1 (Feb - June 2016): beam storage, vacuum scrubbing, optics studies, no collisions

Phase 2 (2018): first collisions, complete Belle II detector except for Vertex Detector

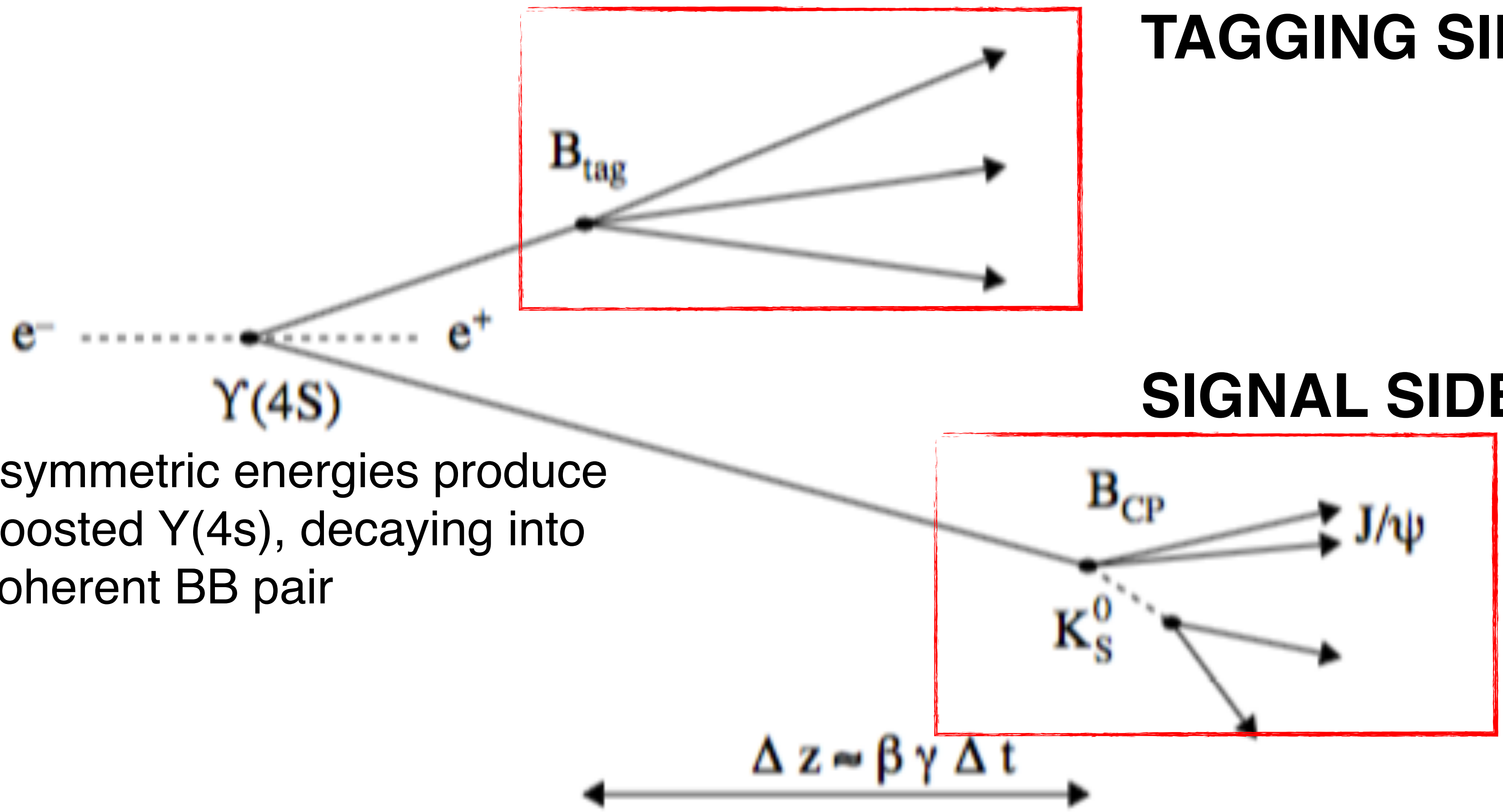
Phase 3 (late 2018 - 2024): full Belle II detector

All plots and performance figures shown today are based on simulation

$\varphi_1,\varphi_2(\beta,\alpha)$: general strategy

decay time-dependent measurements

Interference between B–$\bar{B}$ mixing and B decay amplitudes → time-dependent CP asymmetry



asymmetric energies produce boosted Υ(4s), decaying into coherent BB pair

key aspects:

- Δt resolution→vertex fitting
- Flavour tagger

Δz ~ 130 μm (Belle II)

Δz ~ 200 μm (Belle)

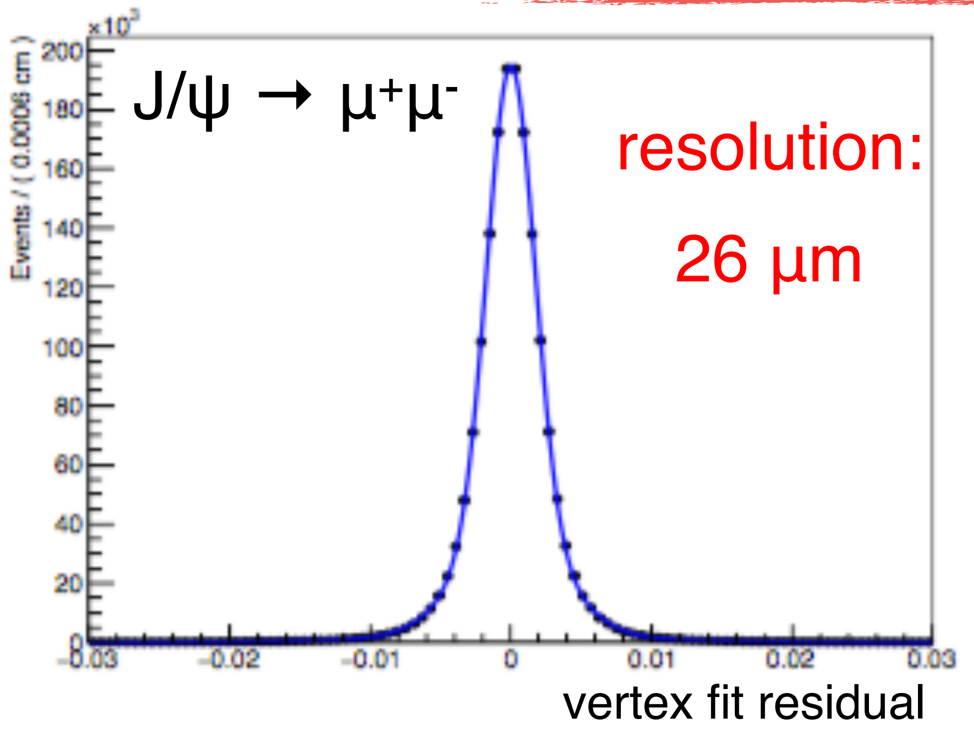
Time-dependent rate asymmetry of B meson decays into CP eigenstates

$$a_{f_{CP}}(\Delta t) = \frac{\Gamma[B(\Delta t)] - \Gamma[\bar{B}(\Delta t)]}{\Gamma[B(\Delta t)] + \Gamma[\bar{B}(\Delta t)]} = C\,cos(\Delta M \Delta t) + S\,sin(\Delta M \Delta t)$$

C = direct CPV

S = $sin(2\phi_i^{eff})$mixing induced CPV

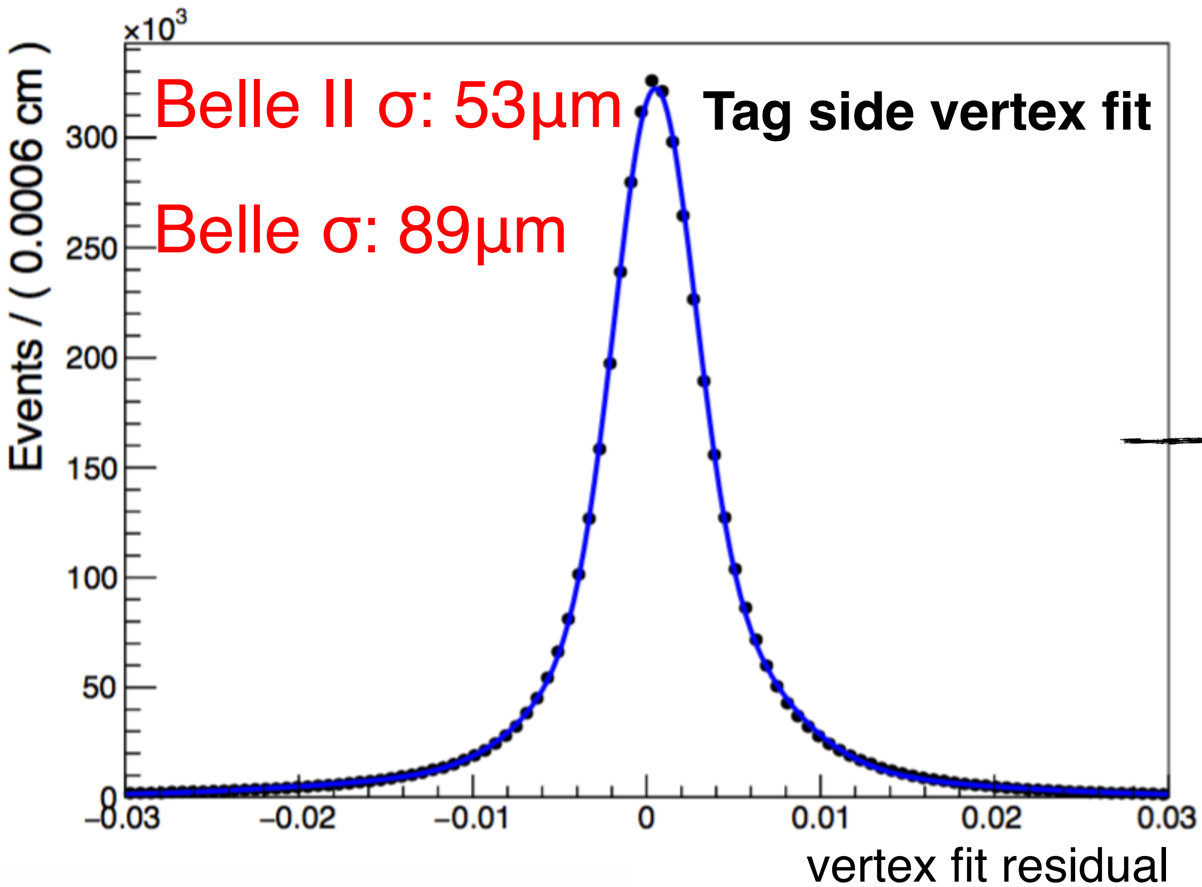
Belle II performance: Vertex fit

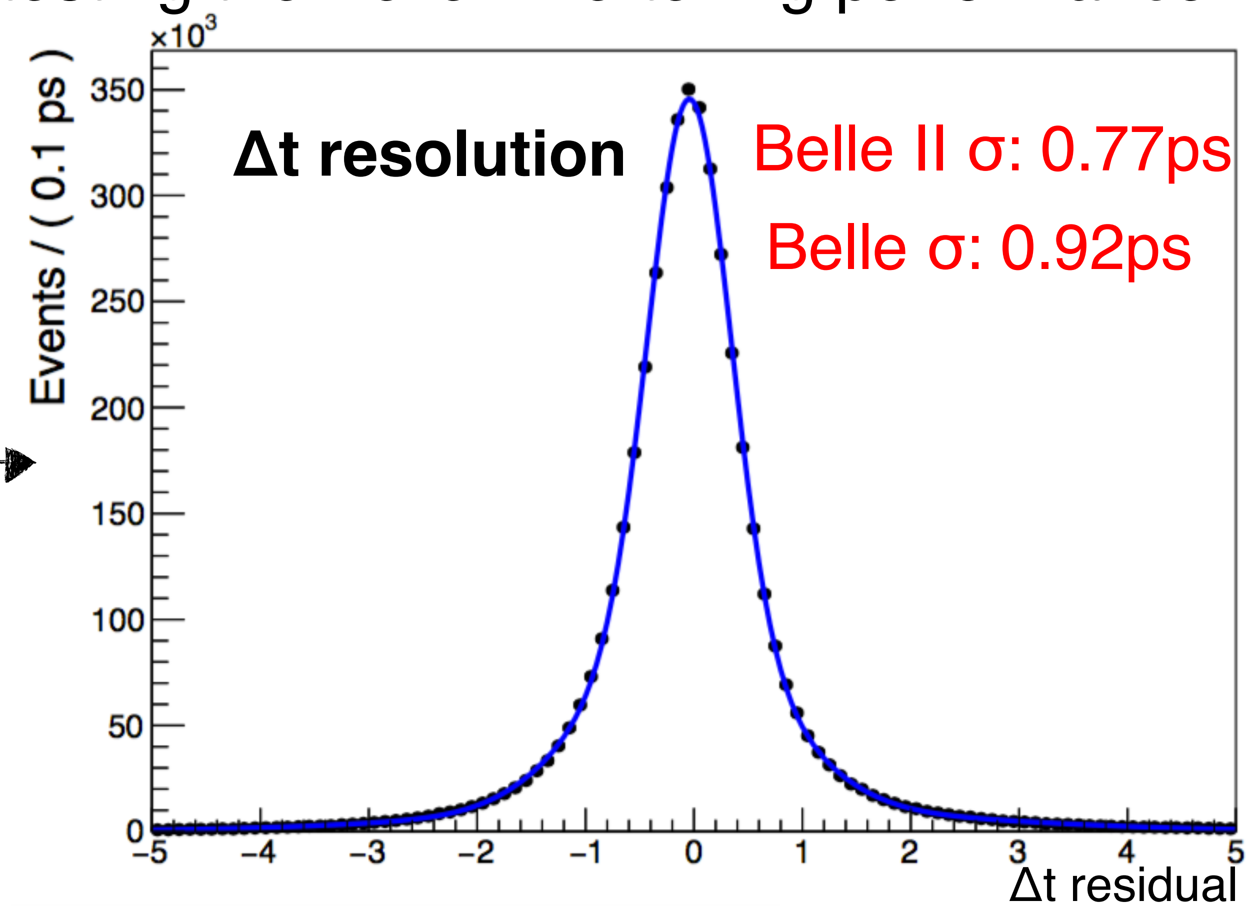


An improvement in vertex-fit position resolution wrt Belle : compatible with the expected improvement in the impact parameter resolution due the Belle II Pixel Vertex Detector

simulation-based plots

$B^0 \to J/\psi\ K^0_s$ decay mode: benchmark for testing the Belle II vertexing performance



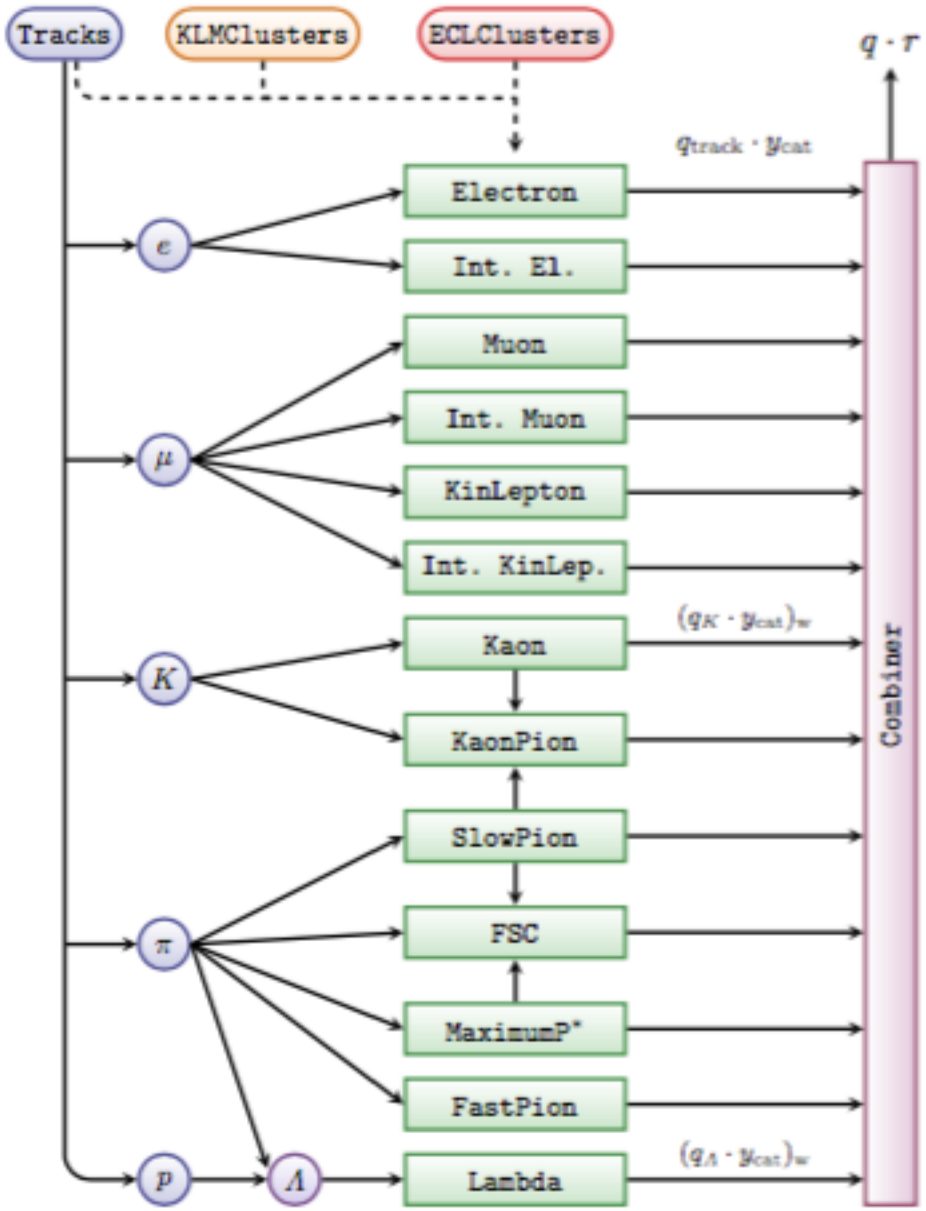


Belle II performance: Flavour tagger

- Determine the flavor of the accompanying B^0 meson at the time of its decay
- Many B decay channels provide unambiguous flavor signatures through a flavor-specific final state but it is unfeasible to fully reconstruct a large number of flavor-specific B_{tag} decays.
- Instead of a full reconstruction, the flavor tagger applies inclusive techniques (in semileptonic $B \to Dl\nu$ decays charge of the lepton identifies the flavour of the B meson)

Advanced tagging algorithm is expected to provide high **tagging efficiency:**

$\varepsilon_{EFF} = 35.84\%$ ($\varepsilon_{EFF}{}^{BELLE} = 30.04\%$)



Belle II tagging categories

$\sin(2\varphi_2)$: *isospin analysis* ($\varphi_2 = \alpha$)

φ_2 can be extracted from mixing-induced CP violation in $b \to u\bar{u}d$ transitions

$$S_{CP} = \sqrt{1 - \mathcal{A}_{CP}^2}\sin(2(\phi_2 + \Delta\phi_2))$$

= 0 at tree-level

but possible penguin pollution!

The most precise way to determine φ_2 is based on applying the isospin [M. Gronau and D. London, PRL 65 3381] measurement to $B \to \pi\pi$ and $B \to \rho\rho$

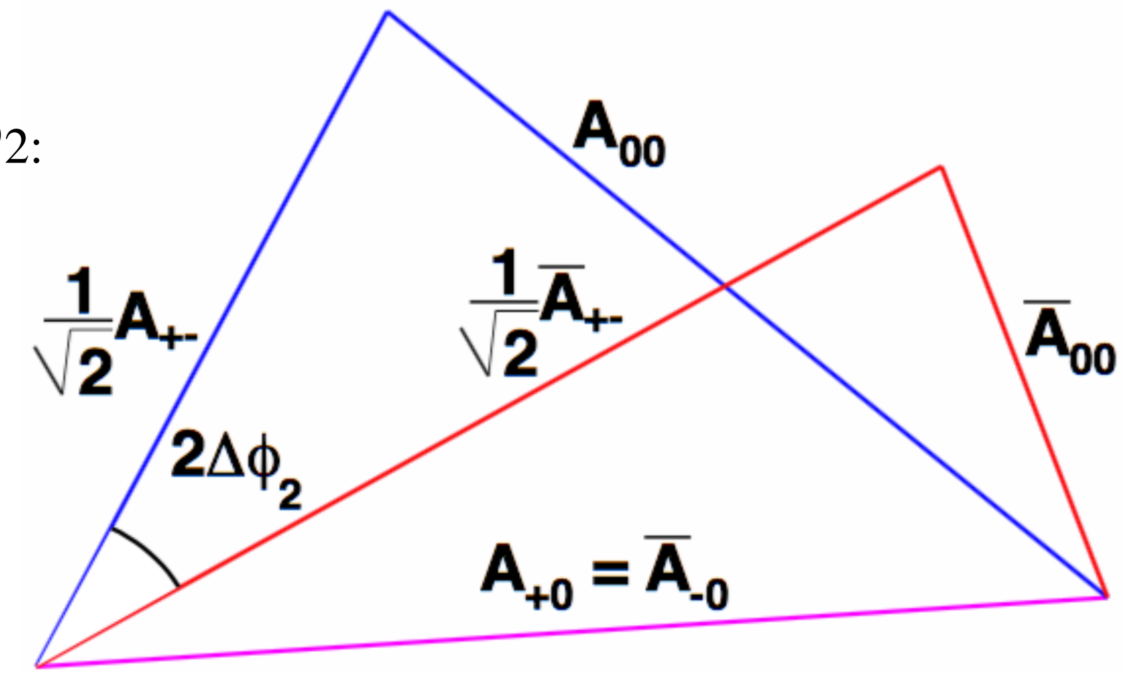
To disentangle the tree contribution and extract $\Delta\phi_2$:

$$\frac{1}{\sqrt{2}}A^{+-} + A^{00} = A^{+0}$$

$$\frac{1}{\sqrt{2}}\bar{A}^{+-} + \bar{A}^{00} = \bar{A}^{-0}$$

$$A^{+0} = \bar{A}^{-0} \text{ (pure tree)}$$

with $\bar{A}^{+-} = \mathcal{A}(\bar{B} \to \rho^+\rho^-)$



currently φ_2 =(94.2±5)°, (166.4±0.8)°

$\sin(2\varphi_2)$: $B \to \pi\pi$ ($\varphi_2 = \alpha$)

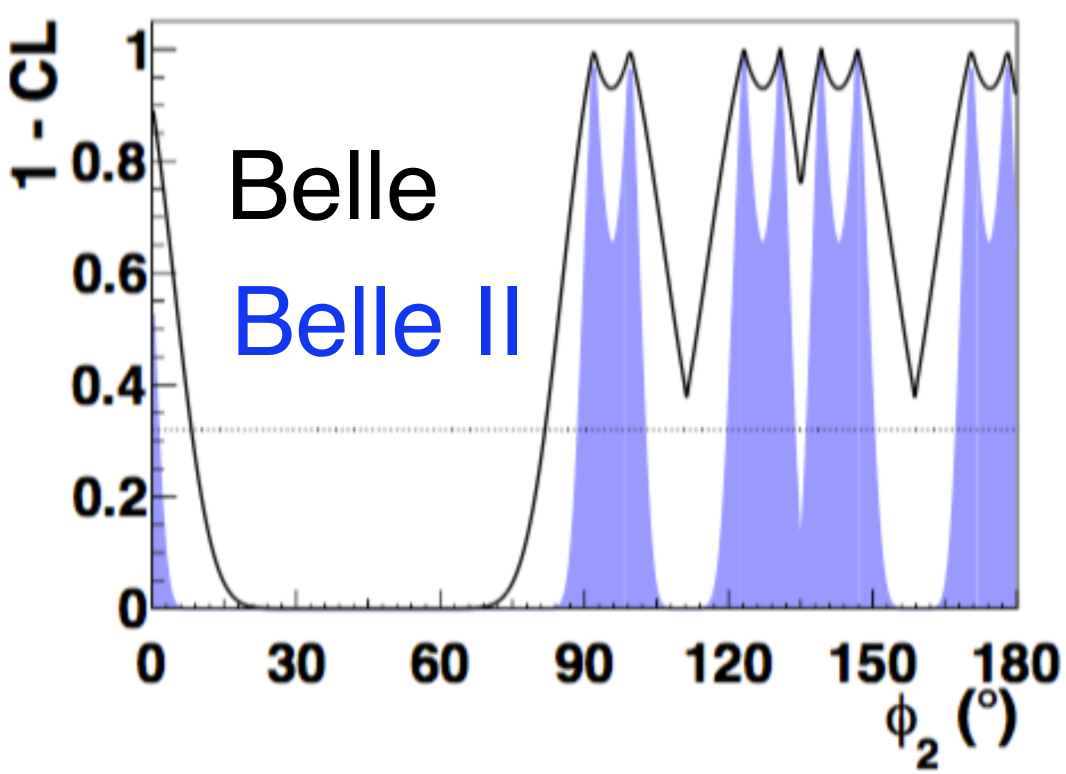
- Branching fractions and CP violation parameters are the input parameters of the isospin analysis
- At present no enough data to perform a time dependent CP-analysis of the decay mode $B \to \pi^0\pi^0$
- $S_{\pi^0\pi^0}$ is an important input for isospin analysis → Belle2 opens new possibilities

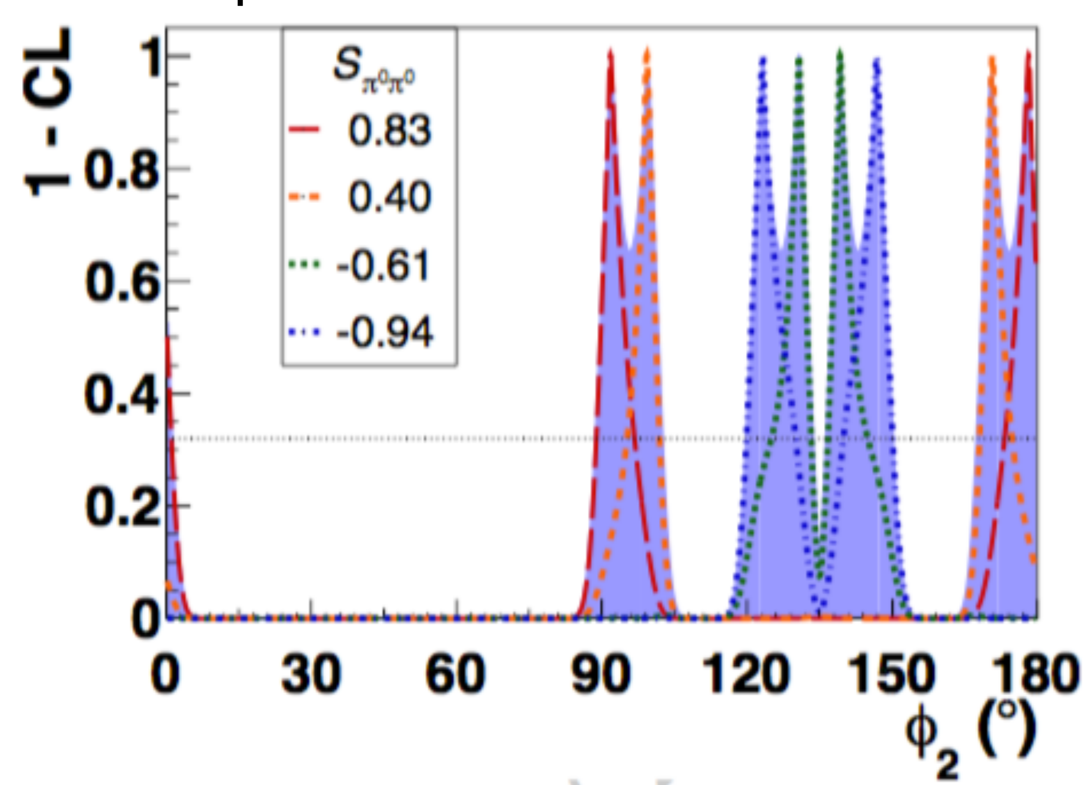
Expected sensitivity at the Belle II integrated luminosity of $50 ab^{-1}$ $\delta\phi_2 = 3°$

Decay modes considered in the $B \to \pi^0\pi^0$:

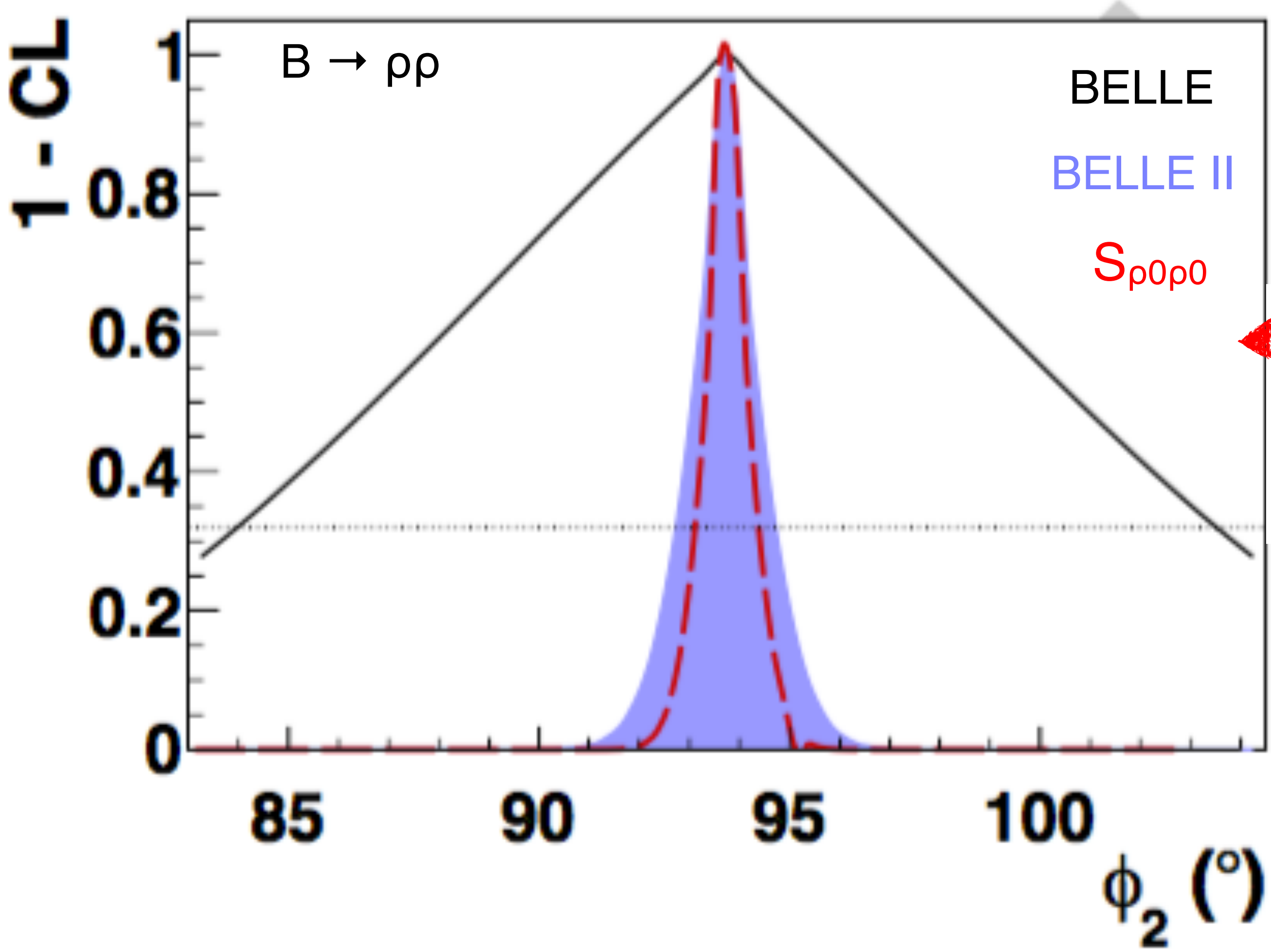
1. $B^0_{\rm sig} \to \pi^0_{\gamma\gamma}(\to \gamma\gamma)\ \pi^0_{\gamma\gamma}(\to \gamma\gamma)$,
2. $B^0_{\rm sig} \to \pi^0_{\rm dal}(\to e^+e^-\gamma)\ \pi^0_{\gamma\gamma}(\to \gamma\gamma)$,
3. $B^0_{\rm sig} \to \pi^0_{\gamma_c\gamma}(\to \gamma_c(\to e^+e^-)\gamma)\ \pi^0_{\gamma\gamma}(\to \gamma\gamma)$.

approximately reconstruction of the B decay vertex for time-dependent CP measurement

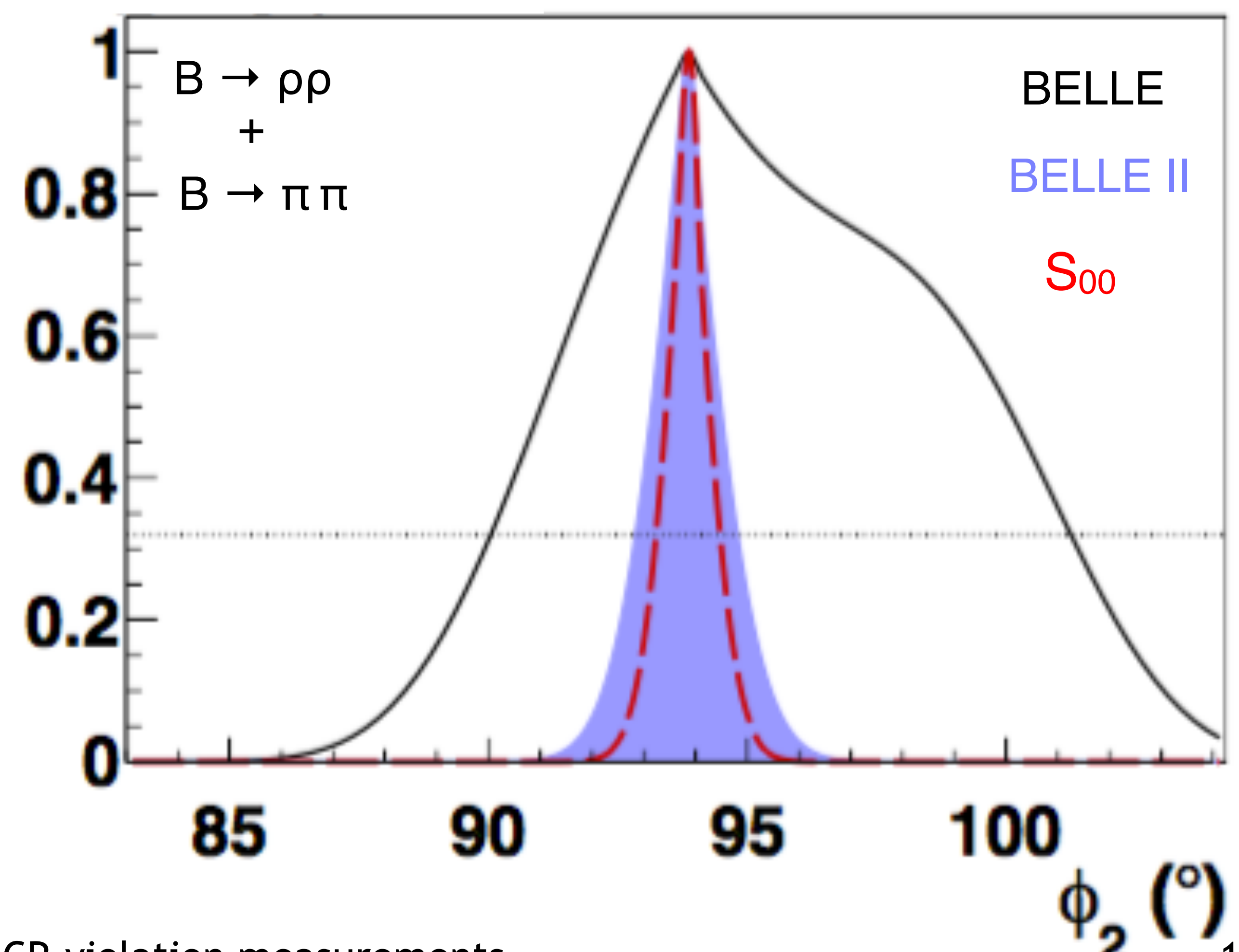




sin(2φ_2): B→ ρρ (φ_2 =α)



Improvement in the B→ ρρ analysis alone and when combined together with B→ ππ

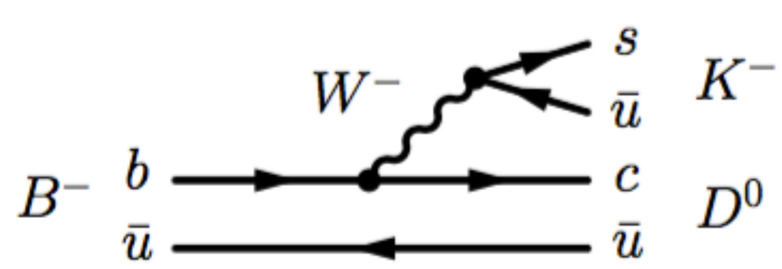


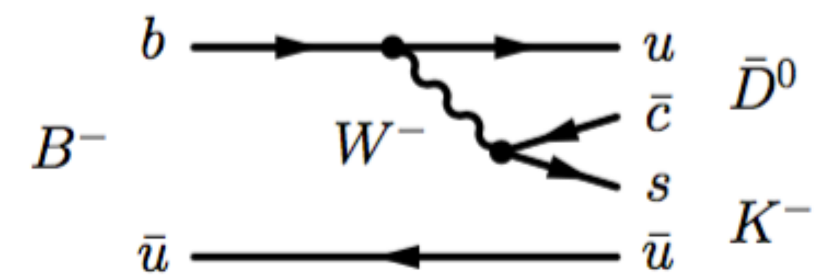
The expected uncertainty on φ_2 with the combined B→ ππ and B→ ρρ is 0.6°

φ_3: B→ DK (φ_3 =γ)

The most powerful methods for measuring this angle are based on the interference between b → c$\bar{u}$s and b → u$\bar{c}$s tree amplitudes with different weak and strong phases in the charged B decays to charm final state: $B^\pm$ → DK.

The tree-level nature of the amplitudes involved in B → DK allows the theoretically clean extraction of ϕ_3 → theoretical ambiguity in such measurements is much less 1%





COLOR-SUPPRESSED

- Direct CP violation ⟶ interference between $B^\pm$ → $DK^\pm$ followed by D → f and $B^\pm$ → $\bar{D}K^\pm$ followed by $\bar{D}$→ f.
- Very challenging ⟶ CKM and color suppression

There are several methods to measure ϕ_3 that can be grouped according to the choice of the final state.

Belle II golden mode: Dalitz-plot analysis of self- conjugate D decays (GGSZ) [PRD68, 054018 (2003)]

$\phi_3 = (78^{+15}_{-16})°$ Belle measurement ⟶ precision on ϕ_3 is an order worse than ϕ_1. Can be improved significantly by experimental advantages alone

$\phi_3 = (76.8^{+5.1}_{-5.7})°$ LHCb measurement

φ_3: GGSZ method ($\varphi_3 = \gamma$)

- The first sensitivity study of Belle II for φ_3 applies the GGSZ analysis of $B^\pm \to (K_s^0\pi^+\pi^-)_D K^\pm$

Dalitz binning used for model- independent analysis

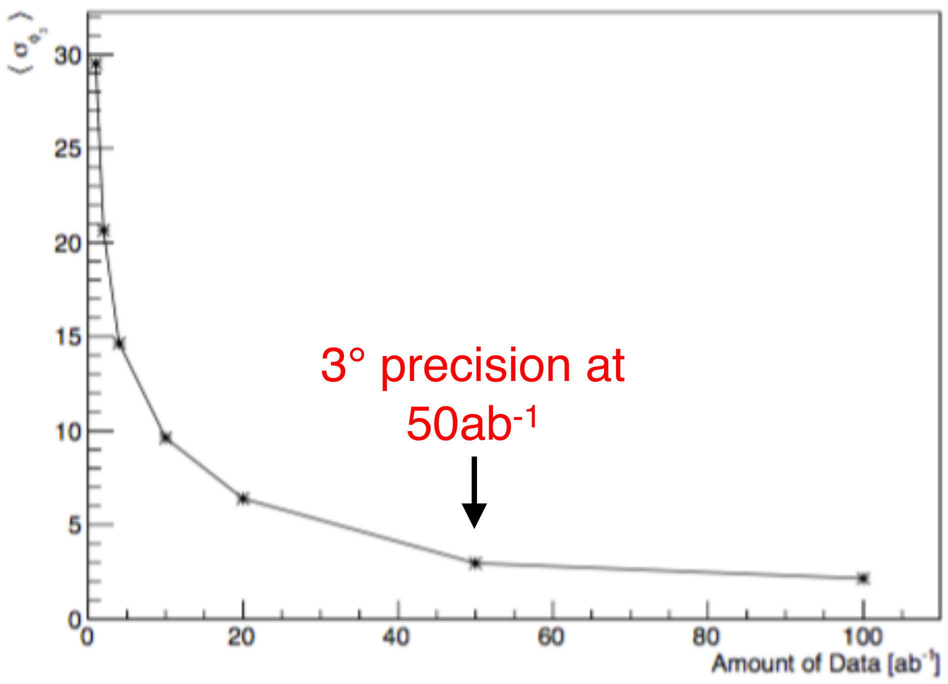
large branching fraction

good K_s^0 reconstruction efficiency

- Dalitz plane is divided into a number of diagonally-symmetric bins.
- For each bin numbers of $B^\pm \to DK^\pm$ decays are measured
- D decay strong phases difference between D and $\bar{D}$ decays for each bin of Dalitz plot are essential inputs to interpret the measurements related to φ_3. (defined on charm-factories, the systematic uncertainty on these measurements will become more significant with future running of both Belle II and LHCb)

expected uncertainty on ϕ_3 versus luminosity (based on toy Monte Carlo studies)

$\delta\phi_3 = 3°$ at 50 ab^{-1}



φ_3: projections ($\varphi_3 = \gamma$)

In Belle measurements using other D decay modes (ADS, GLW techniques) have been performed. Therefore, ϕ_3 programme at Belle II must at least include all these modes and possibly others to realise its full potential.

extrapolation with a combination of other D modes

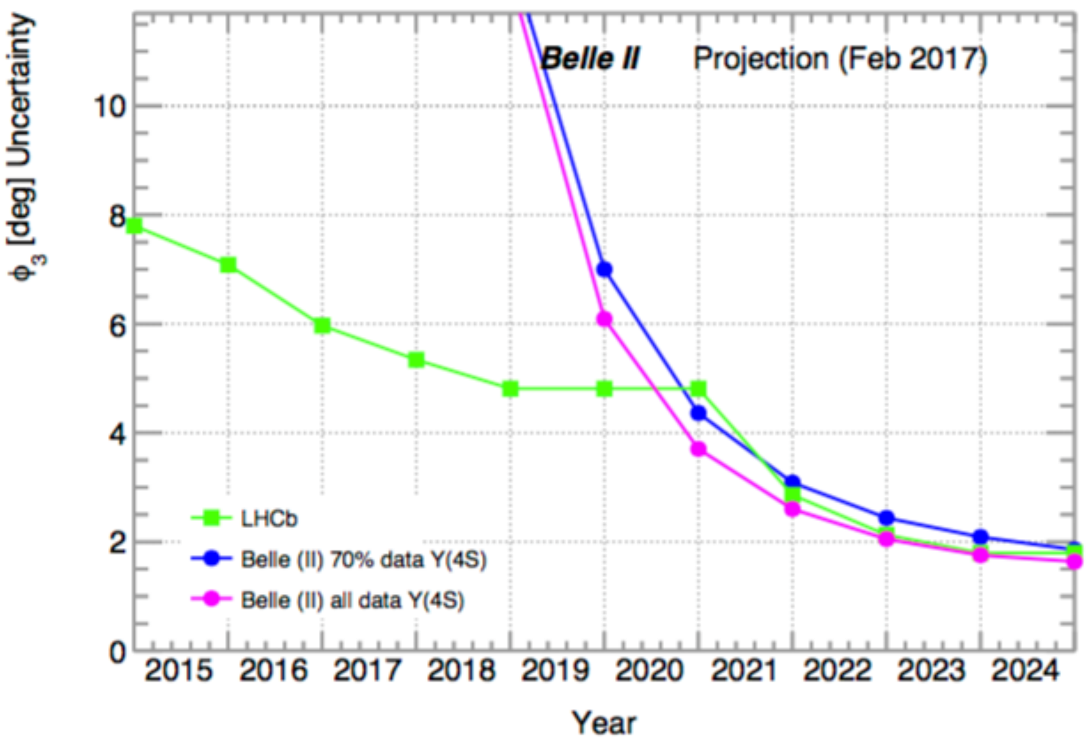
Further improvements are possible as several $B \to DK$ modes have not been exploited in Belle

$\delta\phi_3 = 1.6°$ at 50 ab^{-1}

the extrapolation is predicated on there being sufficient BESIII data collected at the $\psi(3770)$, approximately 10 fb^{-1}, to determine the strong-phase difference parameters required.

Belle II and LHCb will be in competition in ϕ_3 sensitivity:

- LHCb will clearly have more precise results in fully- charged final states
- Belle II sensitivity to neutrals will allows to include more D modes

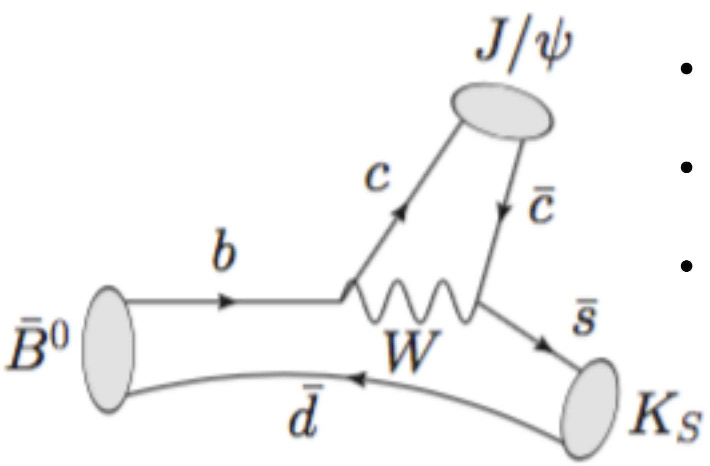


expected sensitivity for LHCb and Belle II experiments

sin($2\varphi_1$) from b → $c\bar{c}s$: status ($\varphi_1 = \beta$)

The angle $\phi 1$ can be measured in processes with a tree dominant interaction ($B \rightarrow J/\psi\, K^0_s$) or with penguin quark transitions ($B \rightarrow \phi\, K^0_{s}$, $B \rightarrow \eta'\, K^0_s$)

The "golden mode" is $B \rightarrow J/\psi\, K^0_{s}$. Advantages of this decay channel for sin$2\phi 1$ measurement:



- clean signature
- relatively large branching fraction, so a large signal yield is expected
- contribution of penguin diagrams expected to be less than 1%

$S_{J/\psi\, K0s} = 0.670 \pm 0.029(\text{stat}) \pm 0.013(\text{syst})$

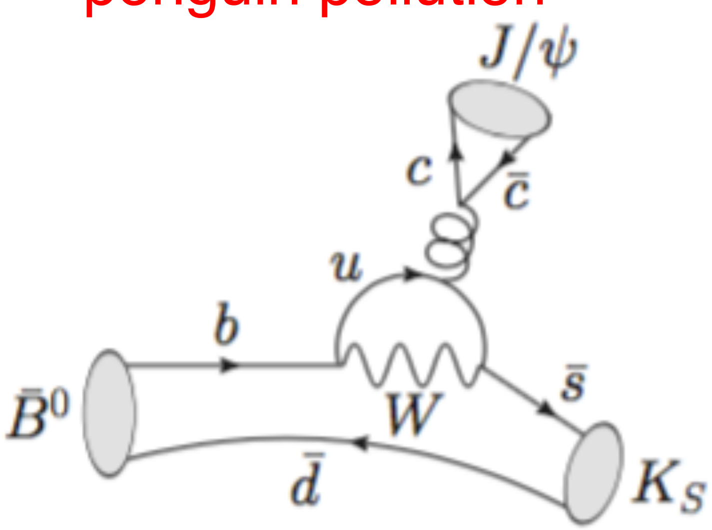
$C_{J/\psi\, K0s} = -0.015 \pm 0.021(\text{stat})\, ^{+0.045}_{-0.045}\, (\text{syst})$

$S_{ccs} = 0.667 \pm 0.023(\text{stat}) \pm 0.012(\text{syst})$

$C_{ccs} = 0.006 \pm 0.016(\text{stat}) \pm 0.012(\text{syst})$

Belle [PRL 108 171802]

penguin pollution



Belle II the measurement will be dominated by systematics

2 irreducible systematic errors:
- tag side interference
- vertex reconstruction

currently $\varphi_1 = (21.4 \pm 0.8)°$

Expected an experimental precision better than 1% on φ_1

$(\varphi_1 = \beta)$

$\sin(2\varphi_1)$ from $b \to q\bar{q}s$

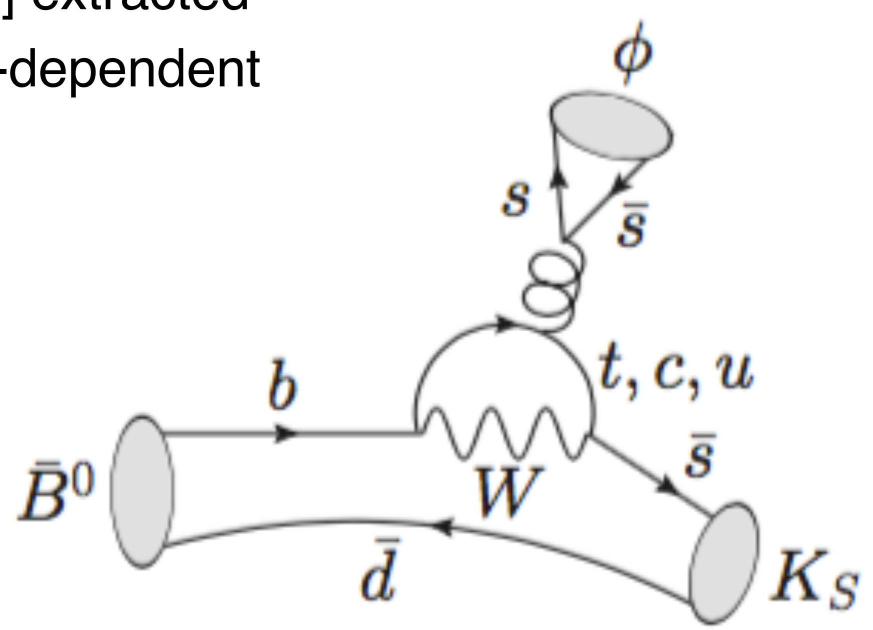
Complementary determination of φ_1 through $b \to qqs$ (q = u, d, s) are dominated by penguin transitions. More sensitive to non SM physics effects.

$B \to \phi K^0_S$

BaBar [arXiv:1201.5897] and Belle [arXiv:1007.3848] extracted the $B_d \to \phi K^0$ CP asymmetry parameters from time-dependent analysis of the $K^+K^-K^0$ final state:

		current value	
ϕK^0	$-\eta S$	0.74	+0.11 -0.13
	A	-0.01	±0.14

average



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

- more complex η’ decay channel
- larger branching fraction (x10)
- no competition with LHCb expected due to neutrals in the final state

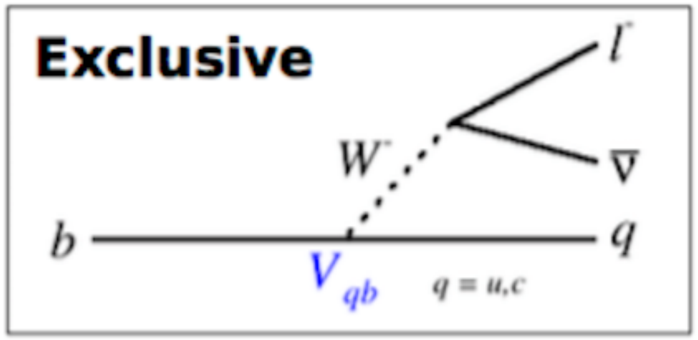
BaBar [arXiv:0809.1174] and Belle [arXiv:1408.5991] collaborations performed the CP-violation analyses for this channel :

$$S_{\eta' K^0_S} = +0.57 \pm 0.08 \pm 0.02 (\mathrm{BaBar})$$

$$S_{\eta' K^0_S} = +0.68 \pm 0.07 \pm 0.03 (\mathrm{Belle})$$

Other CKM measurement: V_{ub}

The $|V_{ub}|$ parameter can be measured through exclusive and inclusive semileptonic B decays

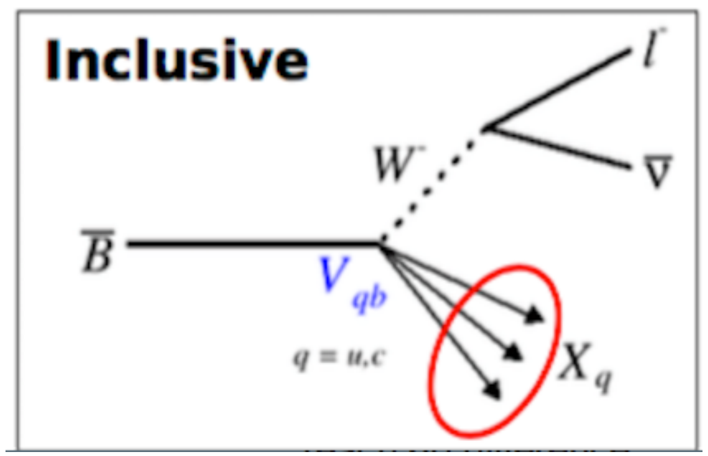


The most promising channel for exclusive $|V_{ub}|$ measurements at Belle II is $B \to \pi l \nu$

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2 |V_{ub}|^2}{24\pi^3} \mathbf{p}_\pi^3 |f_+^{B\pi}(q^2)|^2$$

proportional to $|V_{ub}|$ and to the $B \to \pi$ form factor

Form factor through QCD based calculation.
its uncertainty limits the precision on Vub but a factor 5 improvement is expected



- $B \to X_u l \nu$ rate measurement complicated by $B \to X_c l \nu$ background
- $|V_{ub}|$ is extracted from the differential $B \to X_u l \nu$ rate in various phase space regions
- $|V_{ub}|$ value extracted from the fit to the differential $B \to X_u l \nu$ rates with a fit model defined from simulation.
- predictions of shapes of these functions depend on the dynamic of the decaying b quark → limiting factor for the inclusive $|V_{ub}|$ determination

CURRENT VALUES:

$|V_{ub}^{excl}| = (3.67 \pm 0.09(exp) \pm 0.12(theo)) \times 10^{-3}$

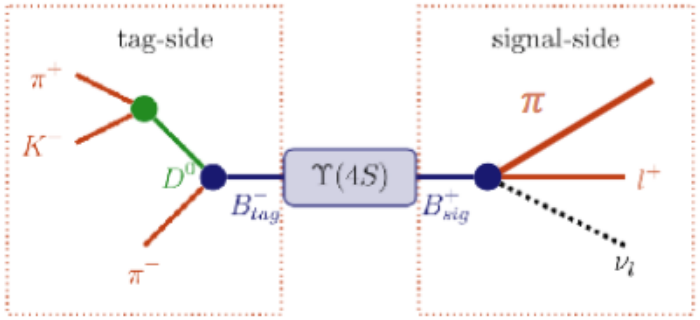
$|V_{ub}^{incl}| = (4.52 \pm 0.15(exp) + 0.11(theo)) \times 10^{-3}$

3 standard deviation discrepancy

V_{ub}: exclusive measurement

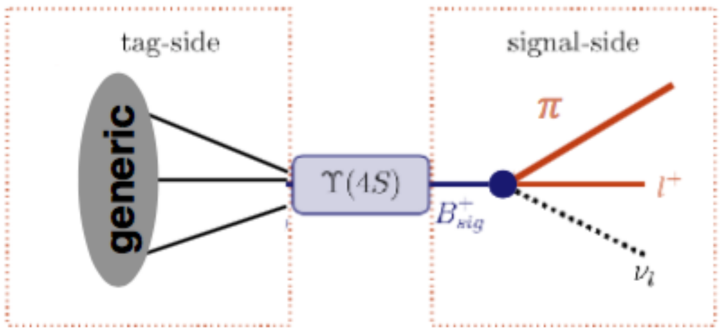
The most promising channel for exclusive $|V_{ub}|$ measurements at Belle II is $B \to \pi l \nu$

"Hadronic Tagged" measurement

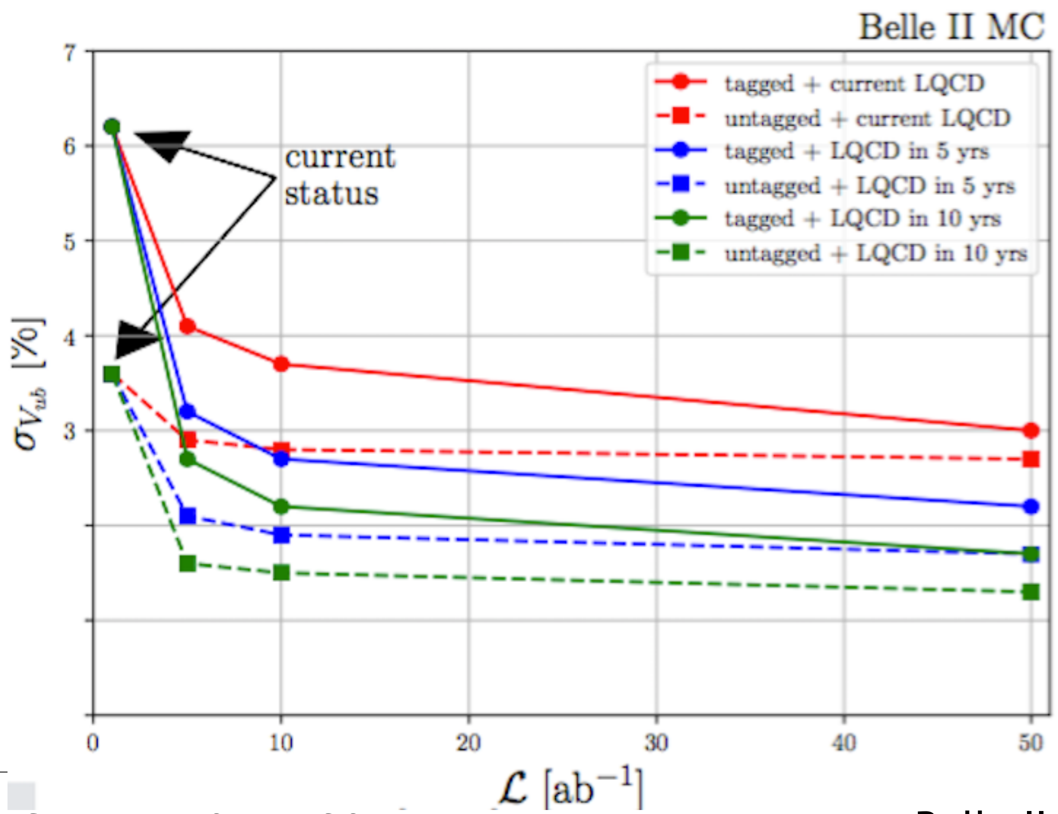


- Exact momentum of companion B gives good q^2 resolution
- $\varepsilon = 0.55\%$ (0.3%@Belle)
- Improvement w.r.t. Belle is due to the better tagging algorithms

"Untagged" measurement



- Indirect determination of companion B momentum spoils q^2 resolution.
- $\varepsilon = 20\%$ (11%@Belle)
- Improvement w.r.t. Belle is due to the better ROE handling



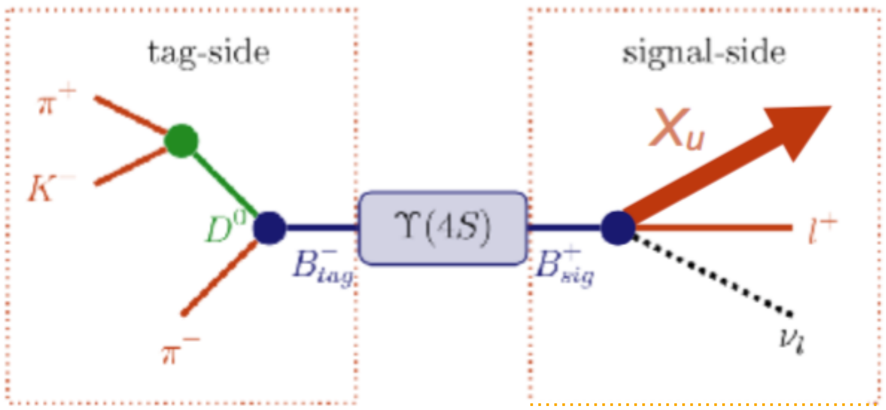
Forecast of $|V_{ub}|$ sensitivity in $B \to \pi l \nu$

Expected precision from $B \to \pi l \nu$ (untagged) = 1.7%

Expected precision from $B \to \pi l \nu$ (tagged) = 1.3%

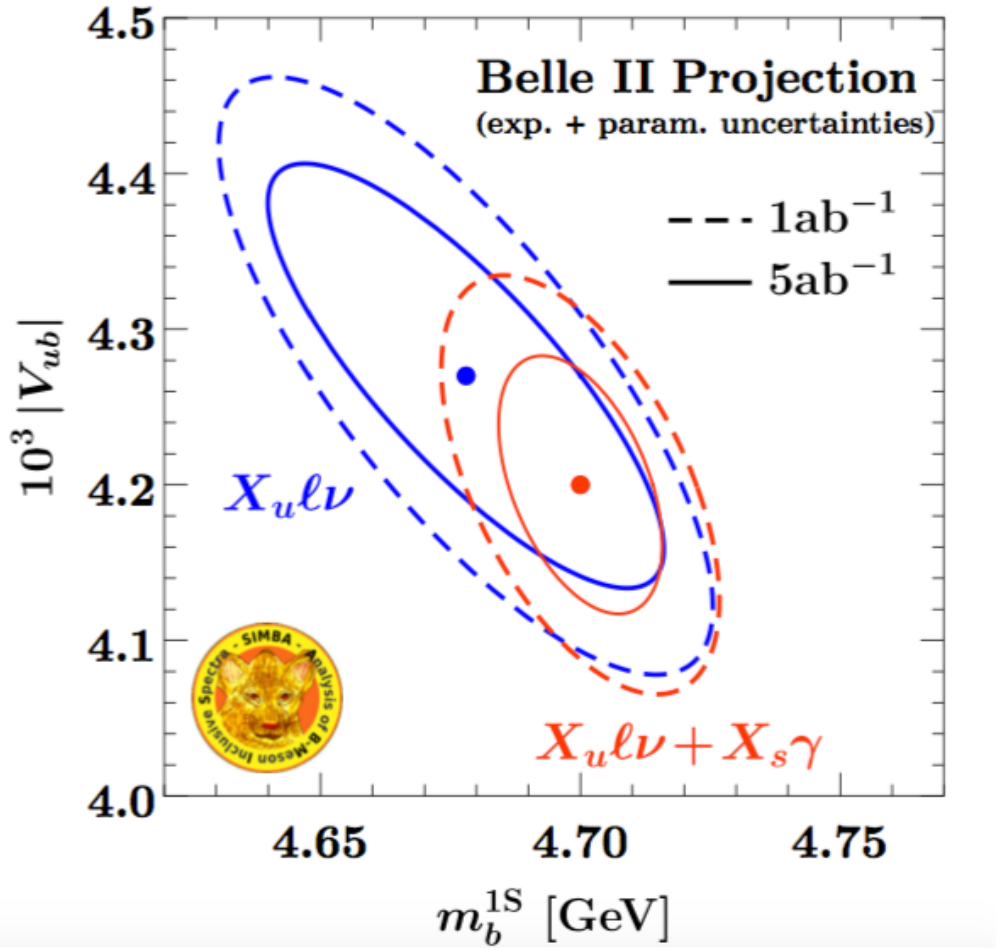
V_{ub}: inclusive measurement

Events with one fully reconstructed tag-side B meson candidate and at least one lepton track for signal candidate are selected



To improve $|V_{ub}|$ precision Belle II will exploit model-independent parametrisation of shape function. [arXiv:0807.1926]

Such parametrisation includes $B \to X_S\gamma$ data (as the dynamic of the b quark in such process coincides with that for the $B \to X_u l \nu$ at leading order)



Projections of global $|V_{ub}|$ fit at Belle II with $1ab^{-1}$ and $5ab^{-1}$ by SIMBA collaboration. Theoretical uncertainties of the same size are not included.

Factor 2 improvement: expected precision of inclusive $|V_{ub}|$ at 5(50) ab^{-1} is 3.4(3)%.

Summary

- Major upgrade at KEK for the next generation B-factory
- Large dataset and improved detector

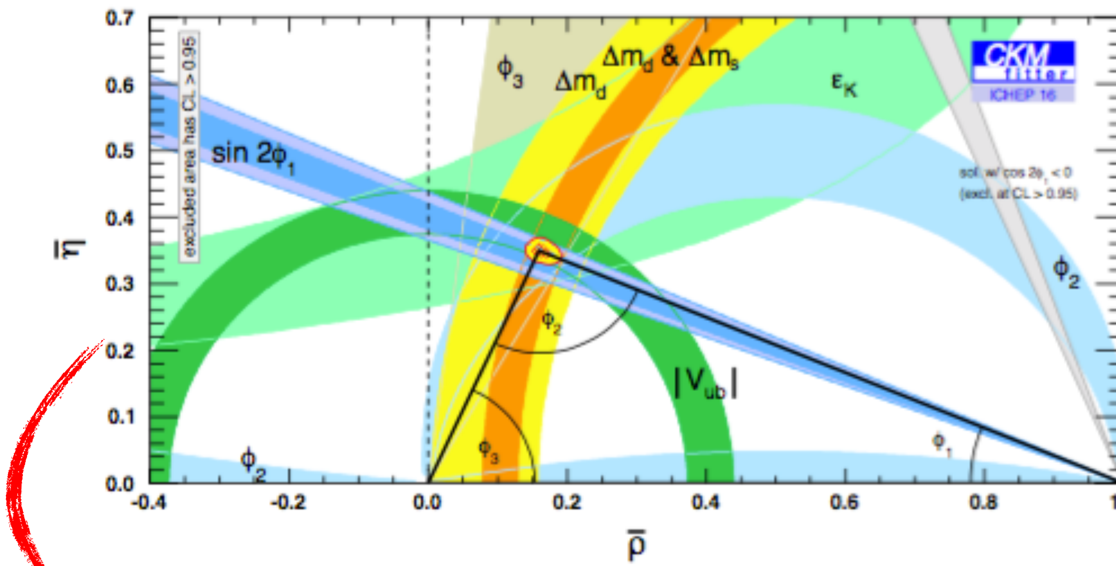
CKM mechanism will be tested at 1% level

- sin($2\varphi_1$): precision better than 1% on φ_1 using $c\bar{c}s$ modes
- sin($2\varphi_2$): new inputs for the isospin analysis. Expected sensitivity $\delta\phi_2$ = 3° at 50 ab^{-1}

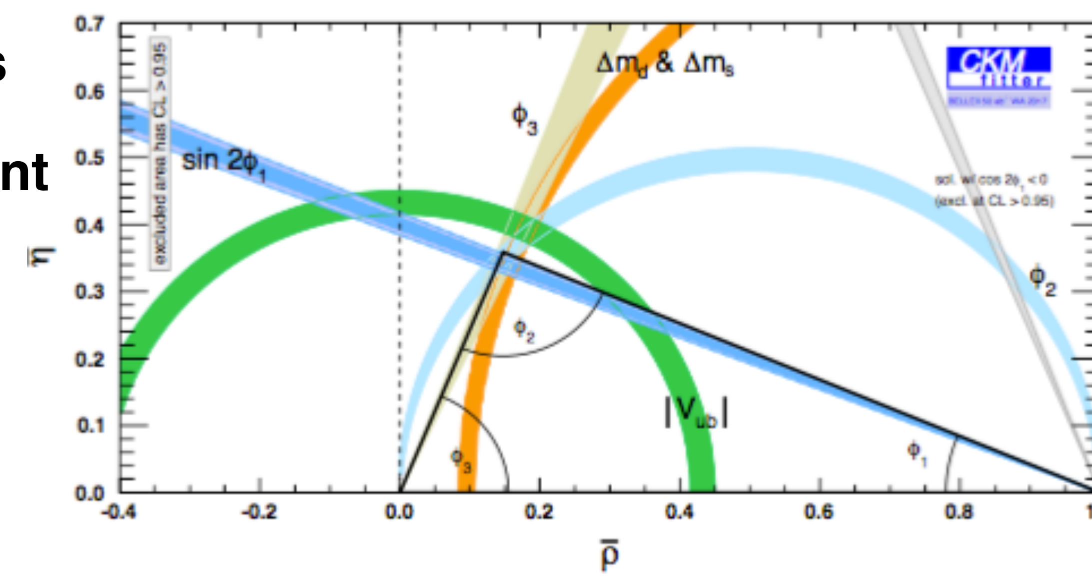
Most likely, the most relevant contribution using CKM physics to probe NP offered by Belle II will be a significant improvement in the determination of ϕ_3 and |V$_{ub}$|:

- φ_3: from $B \to DK$ decays $\delta\phi_3$ = 1.6° at 50 ab^{-1}
- |Vub|: from exclusive (inclusive) semileptonic measurements expected precision of 1.3%(3%)

Current world average



Belle2 projection @ 50ab^{-1}



Backup

Detector components

Purpose	Name	Component	Configuration	Readout	θ coverage	Performance
Beam pipe	Beryllium		Cylindrical, inner radius 10 mm, 12 μm Au (check), 0.6 mm Be, 1 mm paraffin, 0.4 mm Be			
Tracking	PXD	Silicon Pixel (DEPFET)	Sensor size: 15×(L1 136, L2 170) mm^2, Pixel size: 50×(L1a 50, L1b 60, L2a 75, L2b 85) μm^2, Two layers at radii: 8, 12 mm	10M	[17°;150°]	
	SVD	Silicon Strip	Rectangular and trapezoidal, Strip pitch: 50(p)/160(n) - 75(p)/240(n) μm, Four layers at radii: 38, 80, 104, 135 mm	245k	[17°;150°]	
	CDC	Drift Chamber	small cell, large cell	14k	[17°;150°]	
Calorimetry	ECL	CsI(Tl)	Barrel: r = 125 − 162cm, end-cap: z = −102 − +196cm	6624 (Barrel), 1152 (FWD), 960 (BWD)	[12.4°;31.4°], [32.2°;128.7°], [130.7°;155.1°]	$\frac{\sigma E}{E} = \frac{0.2\%}{E} \oplus \frac{1.6\%}{\sqrt[4]{E}} \oplus$ 1.2% ~ 1.7%
Particle ID	TOP	RICH with quartz radiator	16 segments in ϕ at r ~ 120 cm, 275 cm long, 2cm thick quartz bars with 4×4 channel MCP PMTs	8k	[31°;128°]	
	ARICH	RICH with aerogel radiator	2×2 cm thick focusing radiators with different n, HAPD photodetectors FWD	78k	[14°;30°]	
Muon ID	KLM	barrel:RPCs and scintillator strips	2 layers with scintillator strips and 12 layers with 2 RPCs	θ 16k, ϕ 16k	[40°;129°]	
	KLM	end-cap: scintillator strips	14 layers of (7-10)×40 mm^2 strips	17k	[25°;40°], [129°;155°]	
Trigger						

Table 2.1: Summary of the detector components.

Prospects

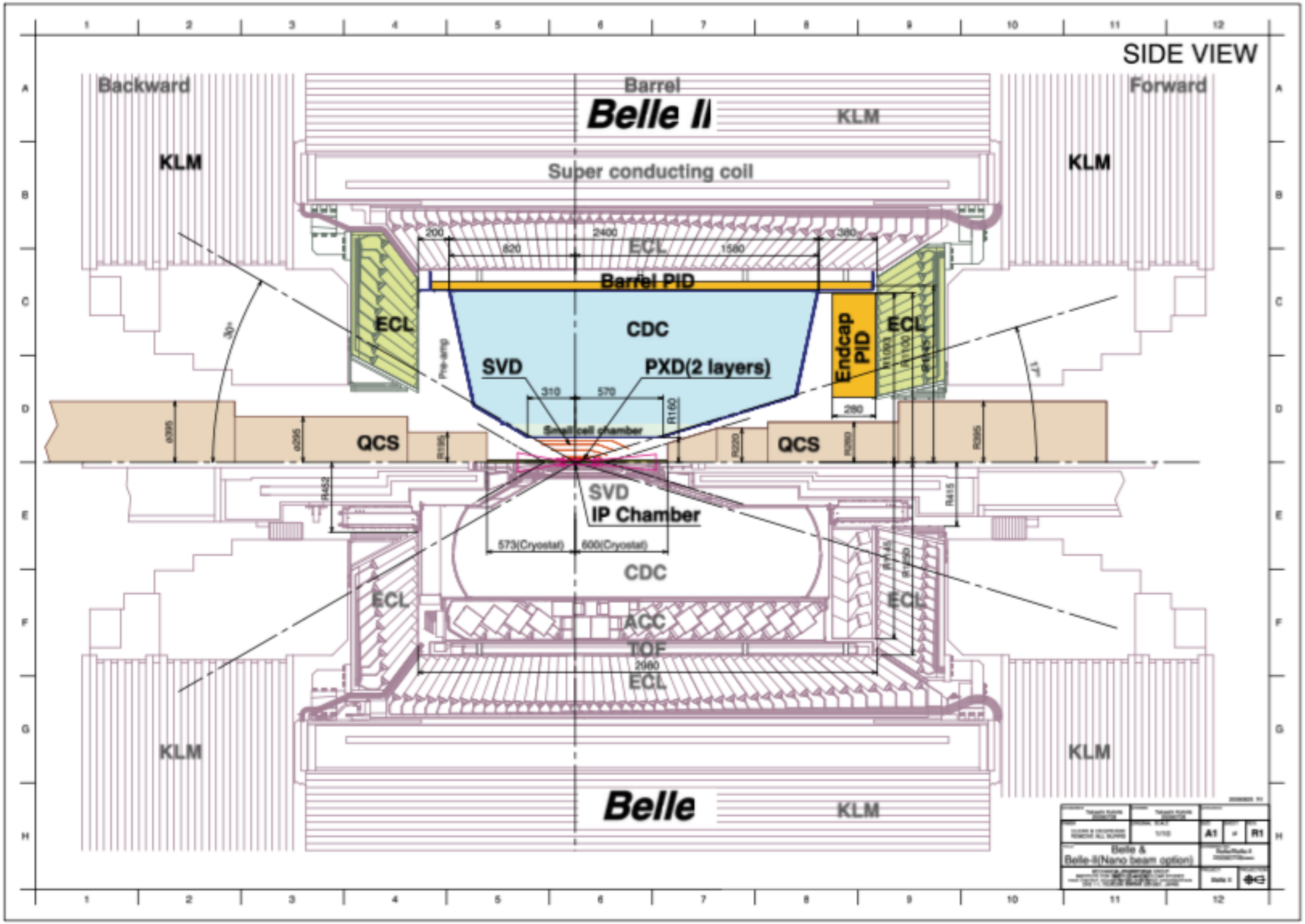
Observables	Expected th. accuracy	Expected exp. uncertainty	Facility (2025)
UT angles & sides			
ϕ_1 [°]	***	0.4	Belle II
ϕ_2 [°]	**	1.0	Belle II
ϕ_3 [°]	***	1.0	Belle II/LHCb
$\|V_{cb}\|$ incl.	***	1%	Belle II
$\|V_{cb}\|$ excl.	***	1.5%	Belle II
$\|V_{ub}\|$ incl.	**	3%	Belle II
$\|V_{ub}\|$ excl.	**	2%	Belle II/LHCb
CPV			
$S(B \to \phi K^0)$	***	0.02	Belle II
$S(B \to \eta' K^0)$	***	0.01	Belle II
$\mathcal{A}(B \to K^0\pi^0)[10^{-2}]$	***	4	Belle II
$\mathcal{A}(B \to K^+\pi^-)$ $[10^{-2}]$	***	0.20	LHCb/Belle II
(Semi-)leptonic			
$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	**	3%	Belle II
$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	**	7%	Belle II
$R(B \to D\tau\nu)$	***	3%	Belle II
$R(B \to D^*\tau\nu)$	***	2%	Belle II/LHCb
Radiative & EW Penguins			
$\mathcal{B}(B \to X_s\gamma)$	**	4%	Belle II
$A_{CP}(B \to X_{s,d}\gamma)$ $[10^{-2}]$	***	0.005	Belle II
$S(B \to K_S^0\pi^0\gamma)$	***	0.03	Belle II
$S(B \to \rho\gamma)$	**	0.07	Belle II
$\mathcal{B}(B_s \to \gamma\gamma)$ $[10^{-6}]$	**	0.3	Belle II
$\mathcal{B}(B \to K^*\nu\overline{\nu})$ $[10^{-6}]$	***	15%	Belle II
$\mathcal{B}(B \to K\nu\overline{\nu})$ $[10^{-6}]$	***	20%	Belle II
$R(B \to K^*\ell\ell)$	**	0.03	Belle II/LHCb

	Observables	Belle or LHCb*	Belle II		LHCb	
		(2014)	5 ab^{-1}	50 ab^{-1}	2018	50 fb^{-1}
Charm Rare	$\mathcal{B}(D_s \to \mu\nu)$	$5.31 \cdot 10^{-3}(1 \pm 5.3\% \pm 3.8\%)$	2.9%	0.9%		
	$\mathcal{B}(D_s \to \tau\nu)$	$5.70 \cdot 10^{-3}(1 \pm 3.7\% \pm 5.4\%)$	3.5%	2.3%		
	$\mathcal{B}(D^0 \to \gamma\gamma)$ $[10^{-6}]$	< 1.5	30%	25%		
Charm CP	$A_{CP}(D^0 \to K^+K^-)$ $[10^{-4}]$	$-32 \pm 21 \pm 9$	11	6		
	$\Delta A_{CP}(D^0 \to K^+K^-)$ $[10^{-3}]$	3.4*			0.5	0.1
	A_Γ $[10^{-2}]$	0.22	0.1	0.03	0.02	0.005
	$A_{CP}(D^0 \to \pi^0\pi^0)$ $[10^{-2}]$	$-0.03 \pm 0.64 \pm 0.10$	0.29	0.09		
	$A_{CP}(D^0 \to K_S^0\pi^0)$ $[10^{-2}]$	$-0.21 \pm 0.16 \pm 0.09$	0.08	0.03		
Charm Mixing	$x(D^0 \to K_S^0\pi^+\pi^-)$ $[10^{-2}]$	$0.56 \pm 0.19 \pm ^{0.07}_{0.13}$	0.14	0.11		
	$y(D^0 \to K_S^0\pi^+\pi^-)$ $[10^{-2}]$	$0.30 \pm 0.15 \pm ^{0.05}_{0.08}$	0.08	0.05		
	$\|q/p\|(D^0 \to K_S^0\pi^+\pi^-)$	$0.90 \pm ^{0.16}_{0.15} \pm ^{0.08}_{0.06}$	0.10	0.07		
	$\phi(D^0 \to K_S^0\pi^+\pi^-)$ [°]	$-6 \pm 11 \pm ^{4}_{5}$	6	4		
Tau	$\tau \to \mu\gamma$ $[10^{-9}]$	< 45	< 14.7	< 4.7		
	$\tau \to e\gamma$ $[10^{-9}]$	< 120	< 39	< 12		
	$\tau \to \mu\mu\mu$ $[10^{-9}]$	< 21.0	< 3.0	< 0.3		

SuperKEKB upgrade

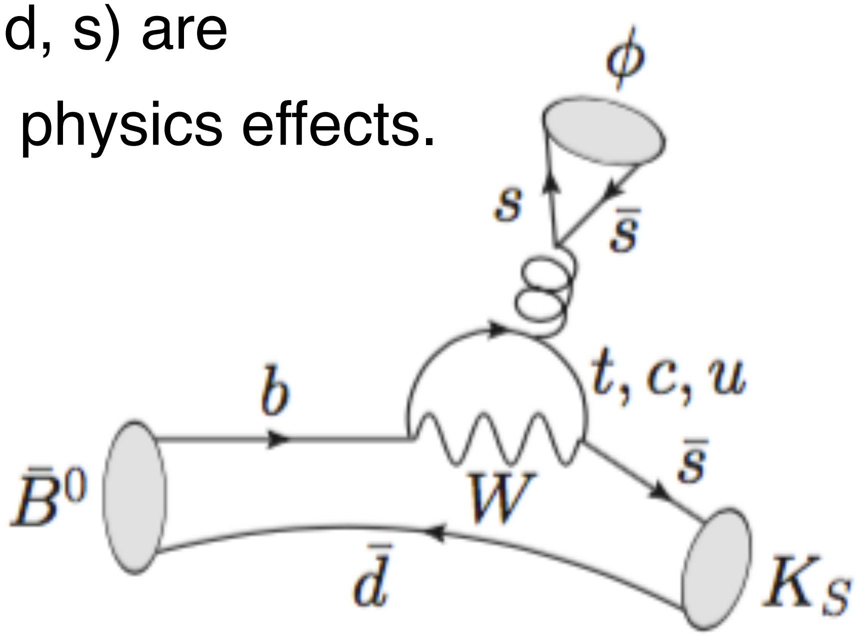
LER / HER	KEKB	SuperKEKB
Energy [GeV]	3.5 / 8	4.0 / 7.0
β_y^* [mm]	5.9 / 5.9	0.27 / 0.30
β_x^* [mm]	1200	32 / 25
$I\pm$ [A]	1.64 / 1.19	3.6 / 2.6
$\zeta_{\pm y}$	0.129 / 0.09	0.09 / 0.09
ε [nm]	18 / 24	3.2 / 4.6
# of bunches	1584	2500
Luminosity [10^{34} cm^{-2} s^{-1}]	2.1	80

Belle 2 detector



$\sin(2\varphi_1)$ from $b \to q\bar{q}s$: $B \to \phi K^0_S$

Complementary determination of φ_1 through $b \to qqs$ (q = u, d, s) are dominated by penguin transitions. More sensitive to non SM physics effects.



BaBar [arXiv:1201.5897] and Belle [arXiv:1007.3848] extracted the $B_d \to \phi K^0$ CP asymmetry parameters from time-dependent analysis of the $K^+K^-K^0$ final state:

		current value		average
ϕK^0	$-\eta S$	0.74	+0.11 -0.13	
	A	-0.01	±0.14	

Channel	Δt resolution (ps)
$\phi(K^+K^-)K_S(\pi^+\pi^-)$	0.75
$\phi(K^+K^-)K_S(\pi^0\pi^0)$	0.77
$\phi(\pi^+\pi^-\pi^0)K_S(\pi^+\pi^-)$	0.78

Sensitivity estimates for $S_{\phi K0}$ and $A_{\phi K0}$ parameters for 1 ab^{-1} and 5 ab^{-1}

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

$\sin(2\varphi_1)$ from $b \to q\bar{q}s$: $B \to \eta' K^0_s$

Differences with respect $B_d \to \phi K^0$:

- more complex η' decay channel
- larger branching fraction (x10)
- no competition with LHCb expected due to neutrals in the final state

BaBar [arXiv:0809.1174] and Belle [arXiv:1408.5991] collaborations performed the CP-violation analyses for this channel :

$$S_{\eta' K^0_S} = +0.57 \pm 0.08 \pm 0.02 (\mathrm{BaBar})$$

$$S_{\eta' K^0_S} = +0.68 \pm 0.07 \pm 0.03 (\mathrm{Belle})$$

estimated resolution

Channel	yield	$\sigma(S)$	$\sigma(C)$
$1\ ab^{-1}$			
$\eta(2\gamma)K^0_S(\pi^\pm)$	969	0.13	0.08
$\eta(2\gamma)K^0_S(2\pi^0)$	215	0.27	0.17
$\eta(3\pi)K^0_S(\pi^\pm)$	283	0.25	0.16
$\rho(\pi^\pm)K^0_S(\pi^\pm)$	2100	0.06	0.07
$\rho(\pi^\pm)K^0_S(2\pi^0)$	320	0.10	0.17
K_S modes	3891	0.065	0.040
K_L modes	1546	0.17	0.11
$K_S + K_L$ modes	5437	0.060	0.038

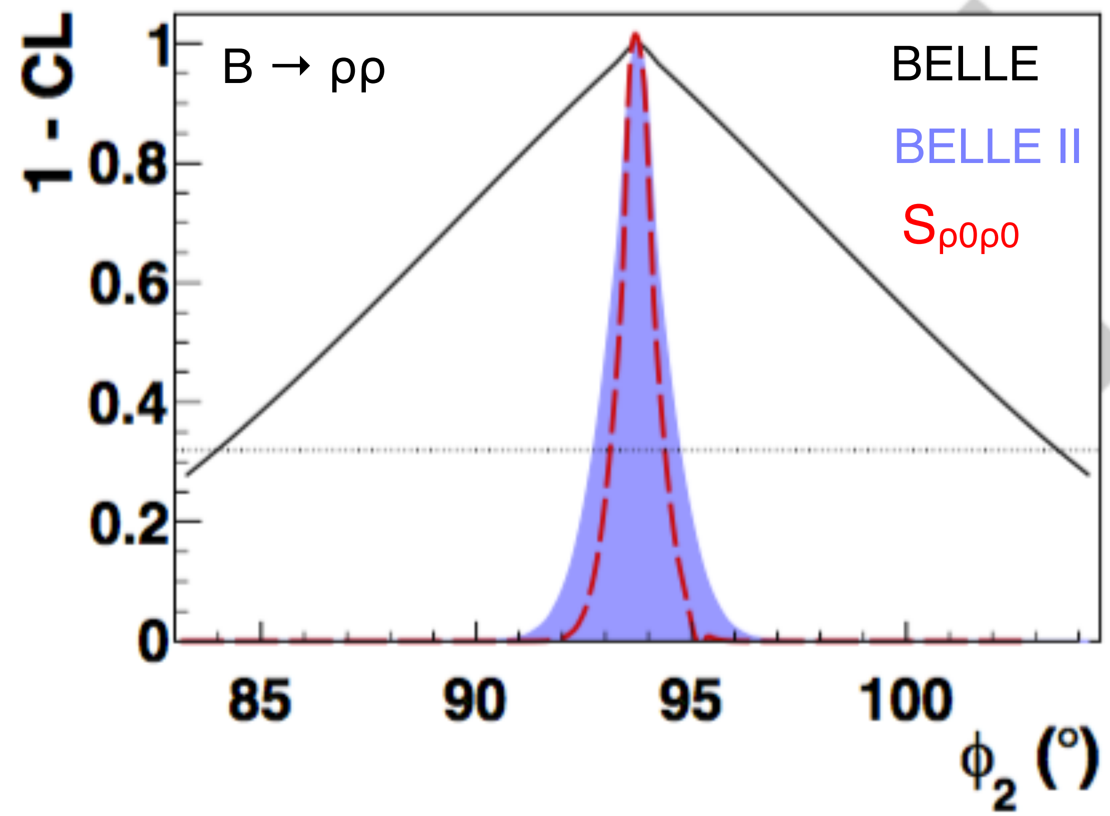
Channel	yield	$\sigma(S)$	$\sigma(C)$
$5\ ab^{-1}$			
$\eta(2\gamma)K^0_S(\pi^\pm)$	4840	0.06	0.04
$\eta(2\gamma)K^0_S(2\pi^0)$	1070	0.12	0.09
$\eta(3\pi)K^0_S(\pi^\pm)$	1415	0.11	0.08
$\rho(\pi^\pm)K^0_S(\pi^\pm)$	10500	0.04	0.03
$\rho(\pi^\pm)K^0_S(2\pi^0)$	1600	0.10	0.07
K_S modes	19500	0.028	0.021
K_L modes	7730	0.08	0.05
$K_S + K_L$ modes	27200	0.027	0.020

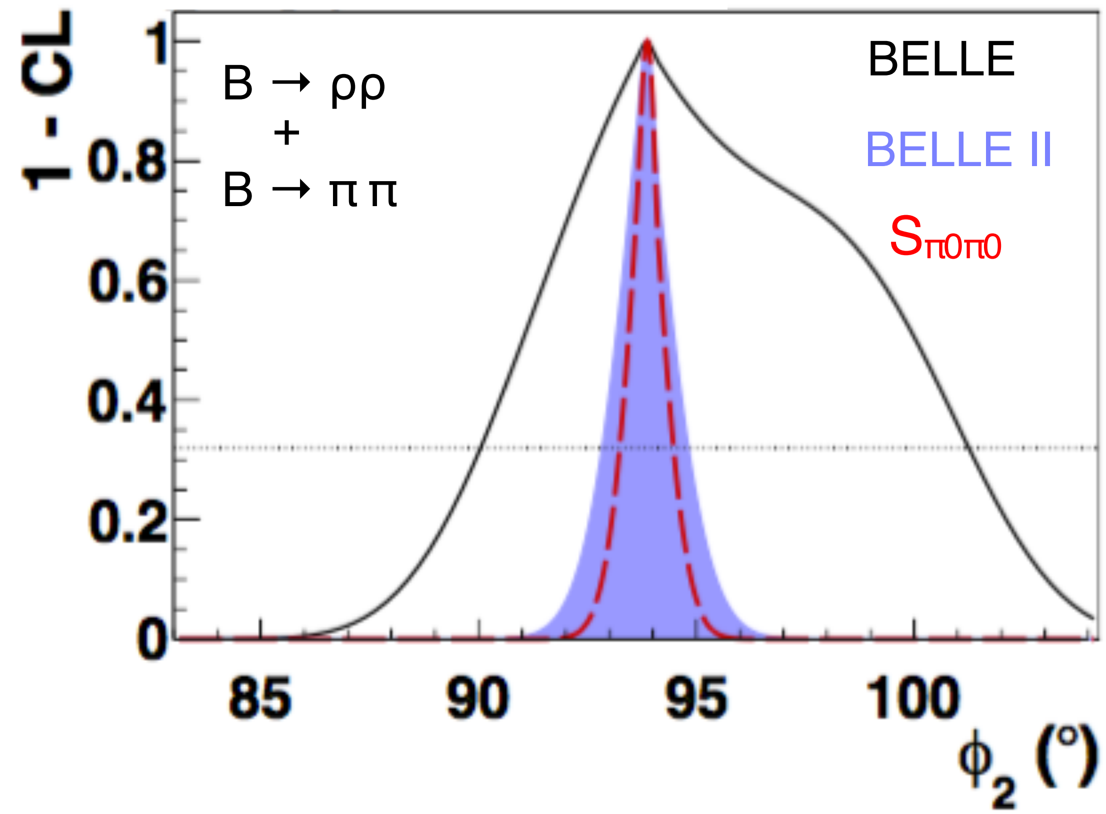
$\sin(2\varphi_2)$: B⟶ ρρ ($\varphi_2 = \alpha$)

Branching fractions, fractions of longitudinally polarised events and CP asymmetry parameters entering in the isospin analysis of the B → ρρ system

		BELLE	BELLE II
	Value	Belle @ 0.8 ab^{-1}	Belle2 @ 50 ab^{-1}
$f_{L,\rho^+\rho^-}$	0.988	$\pm 0.012 \pm 0.023$ [1]	$\pm 0.002 \pm 0.003$
$f_{L,\rho^0\rho^0}$	0.21	$\pm 0.20 \pm 0.15$ [2]	$\pm 0.03 \pm 0.02$
$\mathcal{B}_{\rho^+\rho^-}$ $[10^{-6}]$	28.3	$\pm 1.5 \pm 1.5$ [1]	$\pm 0.19 \pm 0.4$
$\mathcal{B}_{\rho^0\rho^0}$ $[10^{-6}]$	1.02	$\pm 0.30 \pm 0.15$ [2]	$\pm 0.04 \pm 0.02$
$C_{\rho^+\rho^-}$	0.00	$\pm 0.10 \pm 0.06$ [1]	$\pm 0.01 \pm 0.01$
$S_{\rho^+\rho^-}$	−0.13	$\pm 0.15 \pm 0.05$ [1]	$\pm 0.02 \pm 0.01$
	Value	Belle @ 0.08 ab^{-1}	Belle2 @ 50 ab^{-1}
$f_{L,\rho^+\rho^0}$	0.95	$\pm 0.11 \pm 0.02$ [3]	$\pm 0.004 \pm 0.003$
$\mathcal{B}_{\rho^+\rho^0}$ $[10^{-6}]$	31.7	$\pm 7.1 \pm 5.3$ [3]	$\pm 0.3 \pm 0.5$
	Value	BaBar @ 0.5 ab^{-1}	Belle2 @ 50 ab^{-1}
$C_{\rho^0\rho^0}$	0.2	$\pm 0.8 \pm 0.3$ [4]	$\pm 0.08 \pm 0.01$
$S_{\rho^0\rho^0}$	0.3	$\pm 0.7 \pm 0.2$ [4]	$\pm 0.07 \pm 0.01$

[1]: PRD 93(3) 032010, [2]: Add PRD 89 no.11 119903,
[3]: PRL 91 221801, [4]: PRD 78 071104





$\sin(2\varphi_1)$ from $b \to c\bar{c}s$: projections ($\varphi_1 = \beta$)

Belle II the measurement will be dominated by systematics

Three different scenarios:

- "Belle" : Belle irreducible systematic uncertainties are assumed to not improve in Belle II (not realistic)
- "Belle II" : improvement of 50% is assumed for the systematic due to the vertex positions
- "Leptonic categories" : analysis is performed using only the leptonic categories for flavour tagging

$B \to J/\psi K^0_S$	Belle	Belle II	leptonic categories
S (50 ab^{-1})			
stat.	0.0035	0.0035	0.0060
syst. reducible	0.0012	0.0012	0.0012
syst. irreducible	0.0082	0.0044	0.0040
A (50 ab^{-1})			
stat.	0.0025	0.0025	0.0043
syst. reducible	0.0007	0.0007	0.0007
syst. irreducible	$^{+0.043}_{-0.022}$	$^{+0.042}_{-0.011}$	0.011

$b \to ccs$	Belle	Belle II	leptonic categories
S (50 ab^{-1})			
stat.	0.0027	0.0027	0.0048
syst. reducible	0.0026	0.0026	0.0026
syst. irreducible	0.0070	0.0036	0.0035
A (50 ab^{-1})			
stat.	0.0019	0.0019	0.0033
syst. reducible	0.0014	0.0014	0.0014
syst. irreducible	0.0106	0.0087	0.0035

Expected an experimental precision better than 1% on φ_1

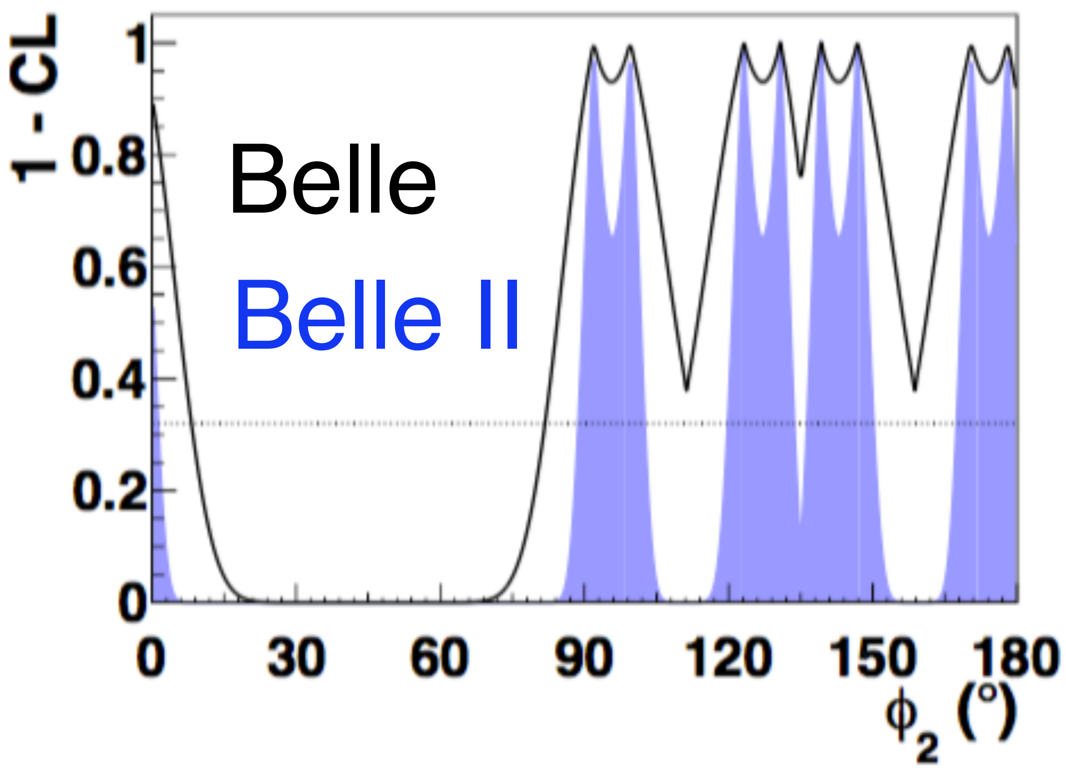
$\sin(2\varphi_2)$: $B \to \pi\pi$ $(\varphi_2 = \alpha)$

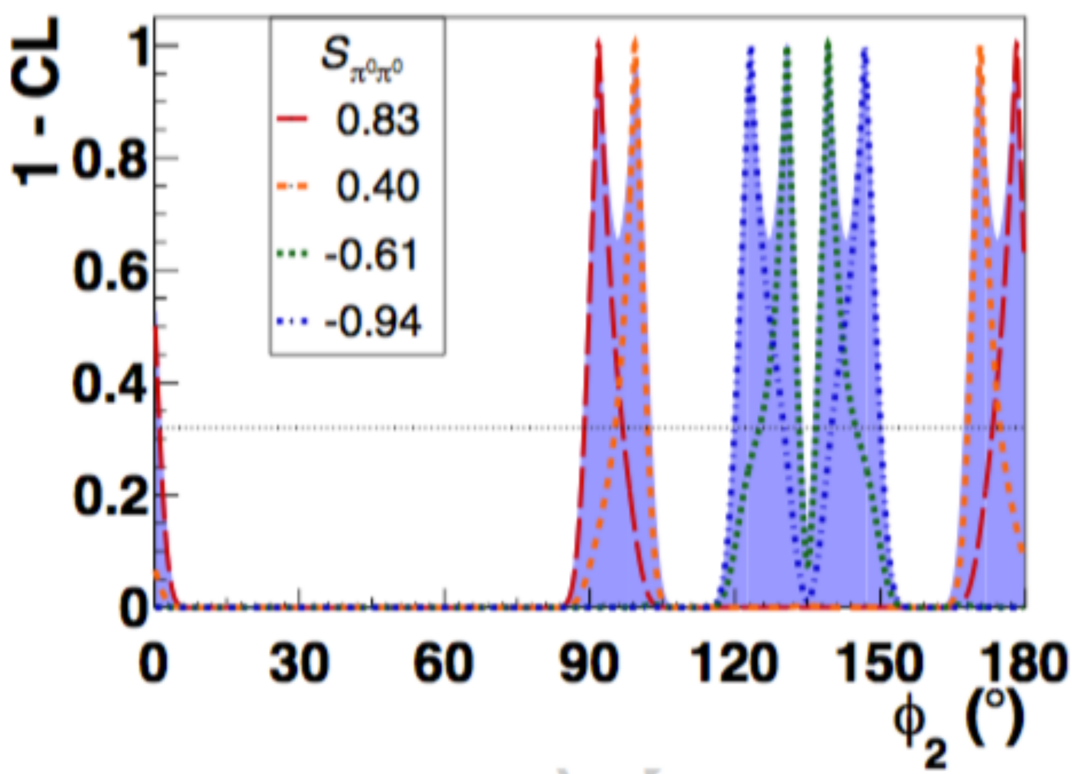
- A scan of the confidence for φ_2 from a $\chi 2$ distribution which is obtained by minimising 2 log(L) is performed. The likelihood L has the form of a multivariate normal distribution:

$$\chi^2 = -2\log\left[\frac{\exp\left(\frac{1}{2}\left(\mathbf{x}_{\mathrm{data}}-\mathbf{x}_{\mathrm{theo}}\right)^T \Sigma^{-1}\left(\mathbf{x}_{\mathrm{data}}-\mathbf{x}_{\mathrm{theo}}\right)\right)}{\sqrt{(2\pi)^n \det \Sigma}}\right].$$

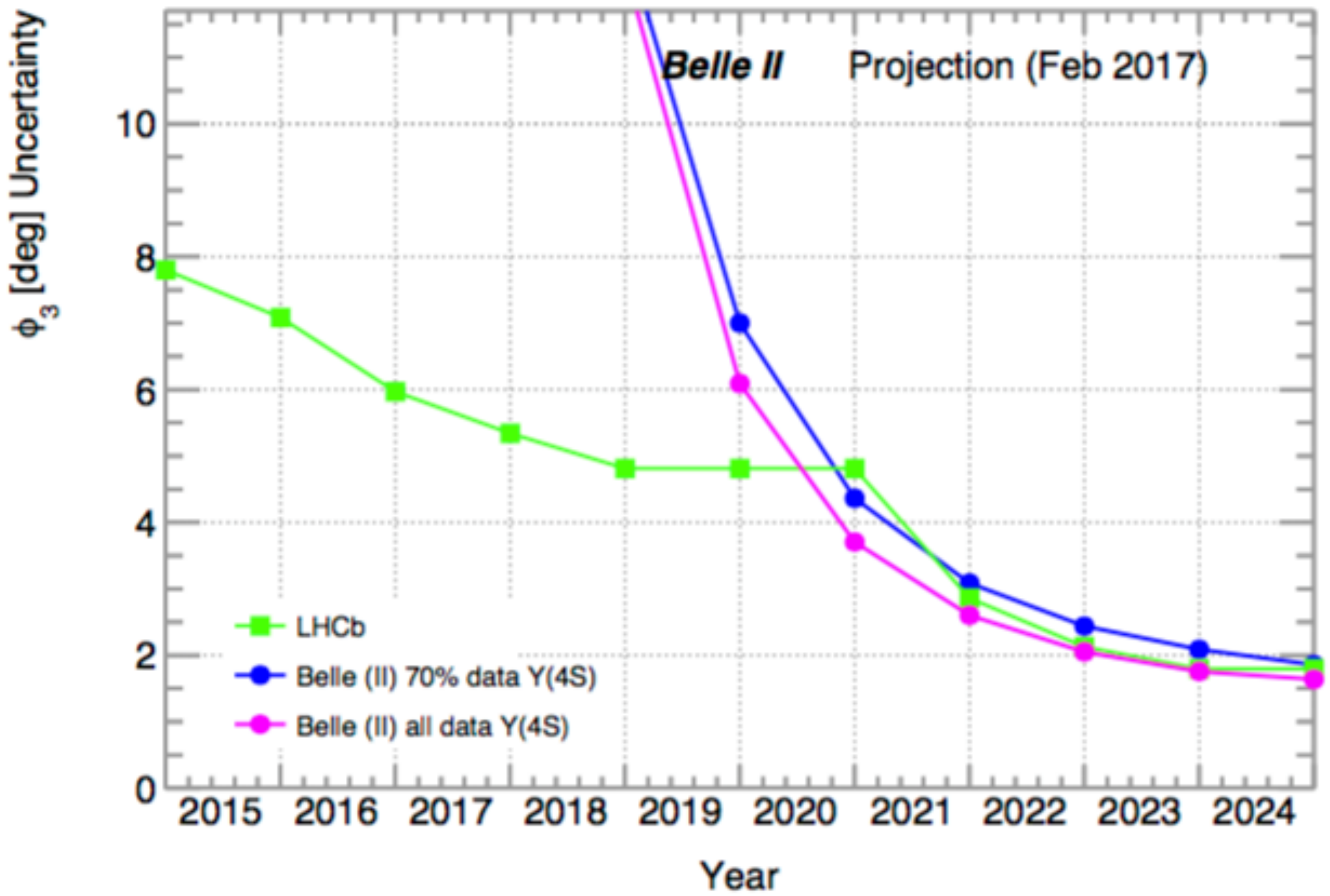
where x_{data} and x_{theo} are vectors containing respectively the measured values and the theoretical prediction of parameters B_{+} , B_{00} , B_{+0} , C_{+} , S_{+} , C_{00} and S_{00}

The covariance matrix Σ contains the uncertainties in the diagonal and the correlations between the measured parameters in the non-diagonal part.





φ_3: LHCb and Belle 2 projections



expected sensitivity for LHCb and Belle II experiments

For Belle II, we base the projections on a combination of $B \to DK$ measurements (already performed at Belle), where the D meson decays to:

- $D \to KK, D \to \pi\pi, D \to K\pi$
- $D \to K\pi\pi\pi$
- $D \to K_S\pi\pi$

where the combined precision on ϕ_3 for Belle is taken from CKMFitter

The LHCb value is based on an extrapolation of the 2015 Run-1 results in LHCb-PAPER- 2014-041 and also analysed by CKMFitter. The results are based on a combination of measurements from $B^+ \to Dh^+$ and $B^0 \to DK^{*0}$ decays, where h^+ corresponds to either K^+ or π^+ and the D meson decays into:

- $D \to KK, D \to \pi\pi, D \to K\pi$
- $D \to K\pi\pi\pi$
- $D \to K_S\pi\pi$

$\sin(2\varphi_1)$ sensitivity

$(\varphi_1 = \beta)$

Table 95: Expected 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 5 and 50 ab^{-1}. The present (2017) World Average [601] errors are also reported.

	WA (2017)		5 ab^{-1}		50 ab^{-1}	
Channel	$\sigma(S)$	$\sigma(A)$	$\sigma(S)$	$\sigma(A)$	$\sigma(S)$	$\sigma(A)$
$J/\psi K^0$	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_S^0	0.21	0.14	0.08	0.06	0.024	0.020
$K_S^0 \pi^0 \gamma$	0.20	0.12	0.10	0.07	0.031	0.021
$K_S^0 \pi^0$	0.17	0.10	0.09	0.06	0.028	0.018