



Quark Flavor Physics Experiments: CP Violation

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ICFA Seminar 2023

Nov. 29, 2023



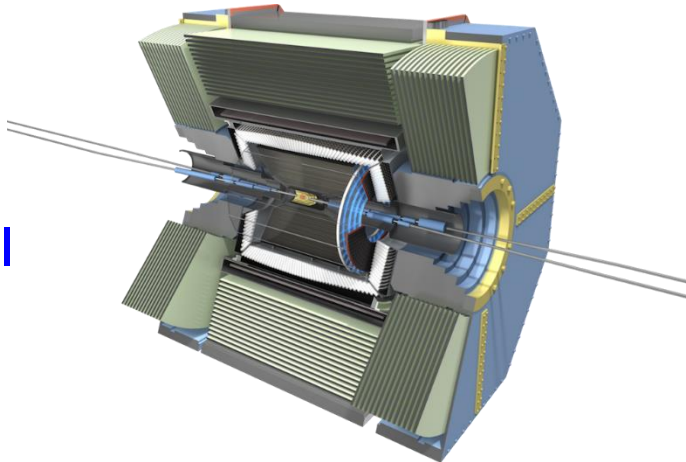
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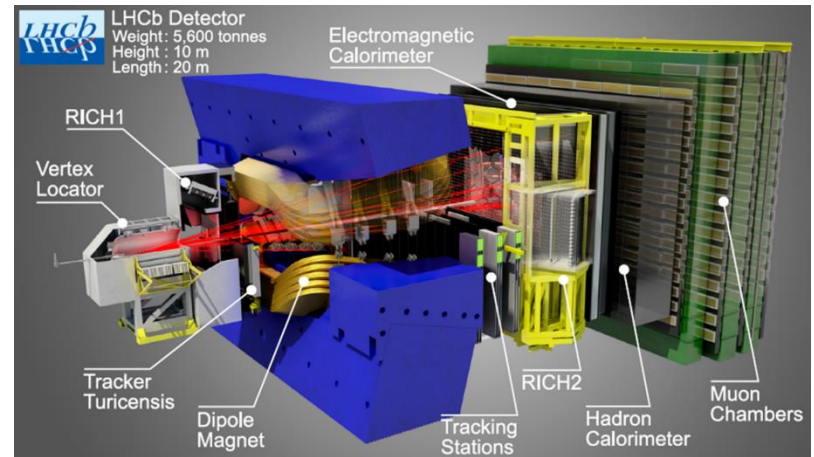
- Introduction
 - ✓ Status of SuperKEKB, Belle II
- Measurements on Unitarity Triangle
 - ✓ $\sin(2\phi_1) / \sin(2\beta)$
 - ✓ ϕ_s
 - ✓ γ / ϕ_3
- Other Measurements, Prospects
- Summary



Belle II

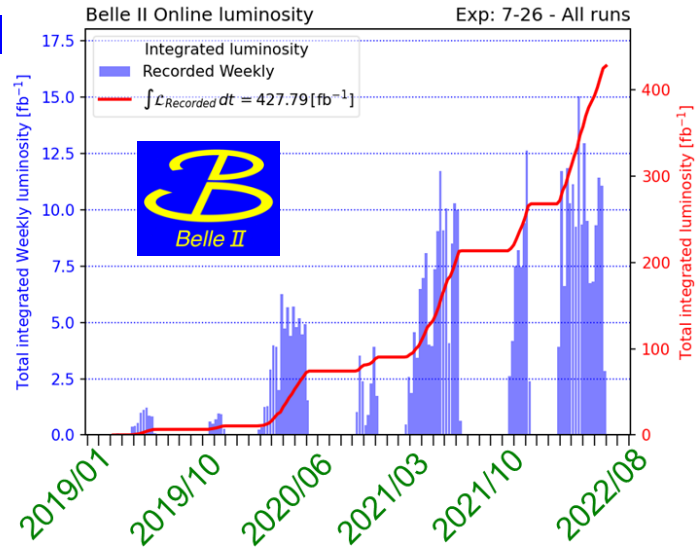
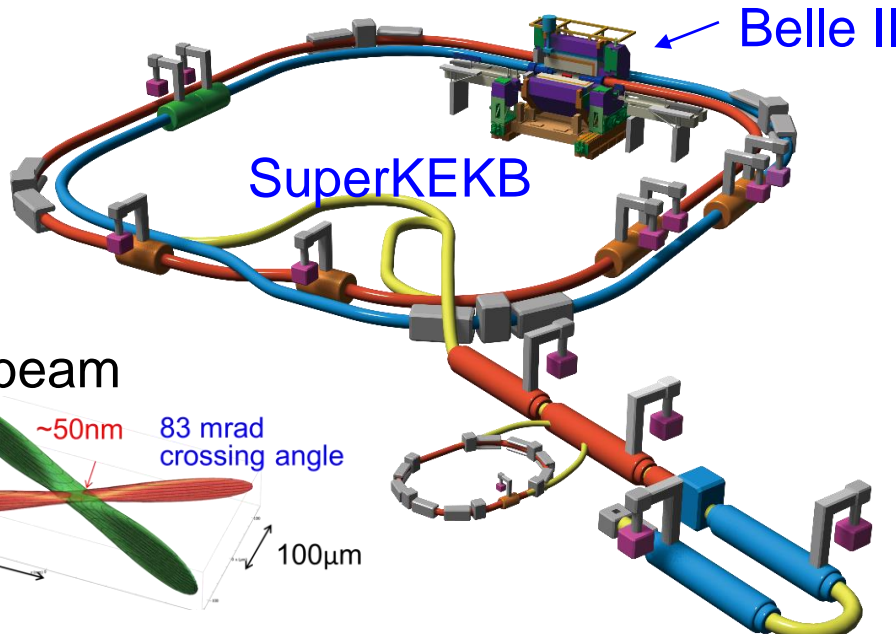


LHCb



- pp collision @ LHC.
- Forward detector optimized for b and c studies.

SuperKEKB and Belle II



Energy scan data above $\Upsilon(4S)$ is taken for bottomonium study.

- e^+e^- collider (4 GeV e^+ + 7 GeV e^-) at KEK.
 - ✓ $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$
- Run1 Operation 2019-2022.
- Long shutdown (LS) 1 from summer 2022 to fully install the pixel detector (PXD).
- Run2 Operation starts from Jan. 2024.

- Luminosity $4.7 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ achieved (Jun. 2022):
 - ✓ World record ($\sim \times 2$ of KEKB)
 - ✓ Aiming one order higher.
- 424 fb^{-1} of data accumulated so far.
 - ✓ Similar to BaBar data set.
 - ✓ Belle: 1 ab^{-1} in 11 years.
 - ✓ Belle II target: 50 ab^{-1} .

CP Violation and KM theory



- CP violation: a key for the matter-antimatter asymmetry.
- Kobayashi-Maskawa theory (1973)
 - ✓ CP violation in the Standard Model (SM)
 - ✓ Complex phase in the quark mixing matrix



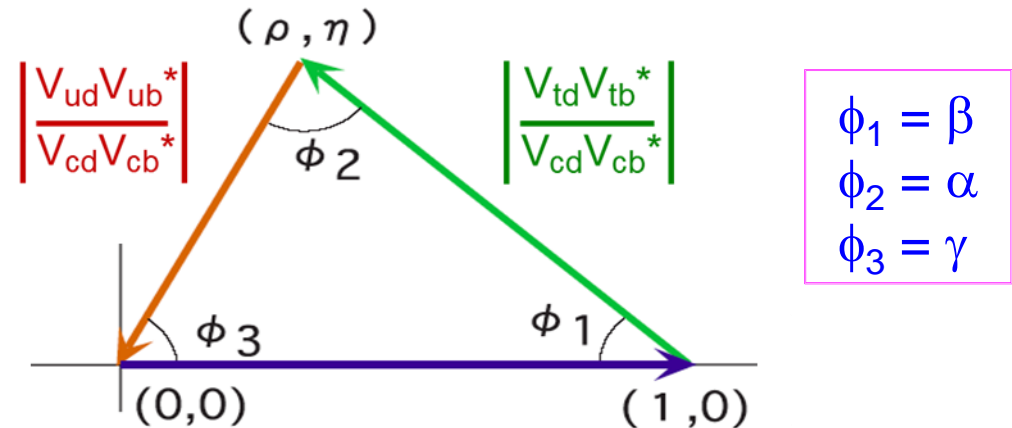
CKM (Cabibbo-Kobayashi-Maskawa) Matrix

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1 - \lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \lambda^2/2 & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

From the unitarity of the matrix:

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

- Triangles in the complex plane.
- Other triangles exist.



CP Violation in B Meson



Mixing-induced CP asymmetry of B mesons

- B^0 and \bar{B}^0 decay to a common CP eigenstate f_{CP} .
- CP violation appears as a decay time difference.

$$A_{CP}(\Delta t) = \frac{\Gamma(\bar{B}^0(\Delta t) \rightarrow f_{CP}) - \Gamma(B^0(\Delta t) \rightarrow f_{CP})}{\Gamma(\bar{B}^0(\Delta t) \rightarrow f_{CP}) + \Gamma(B^0(\Delta t) \rightarrow f_{CP})}$$

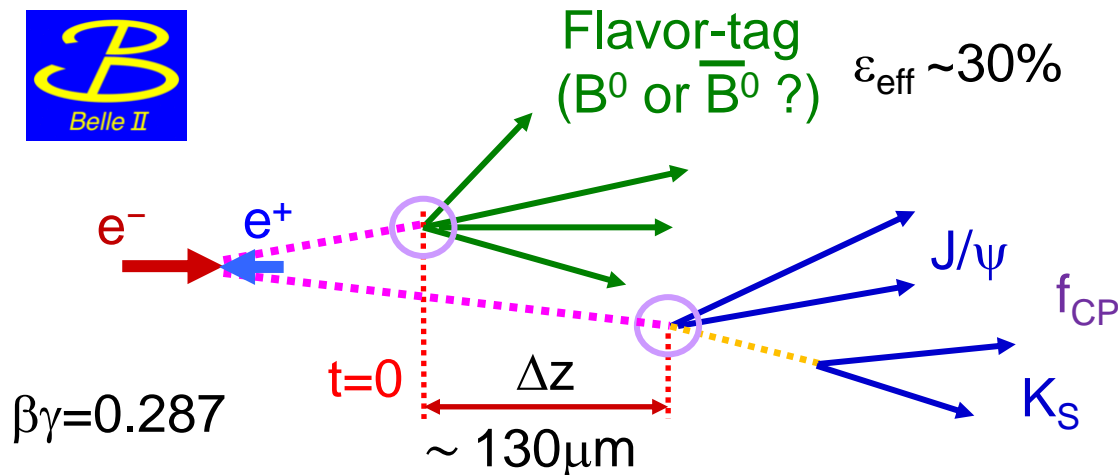
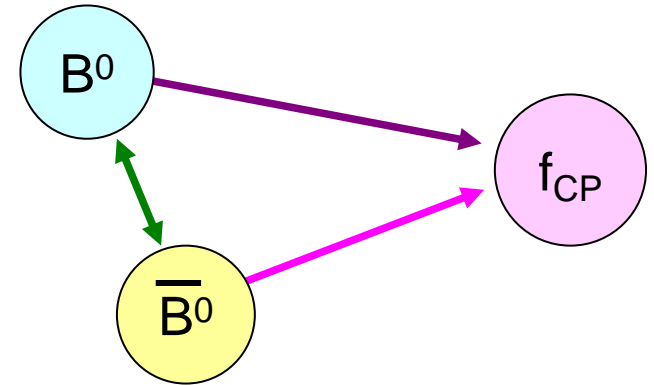
$$= S \sin(\Delta m \Delta t) - C \cos(\Delta m \Delta t)$$

$$S = -\xi \sin(2\phi_1) \text{ for } B \rightarrow J/\psi K_S$$

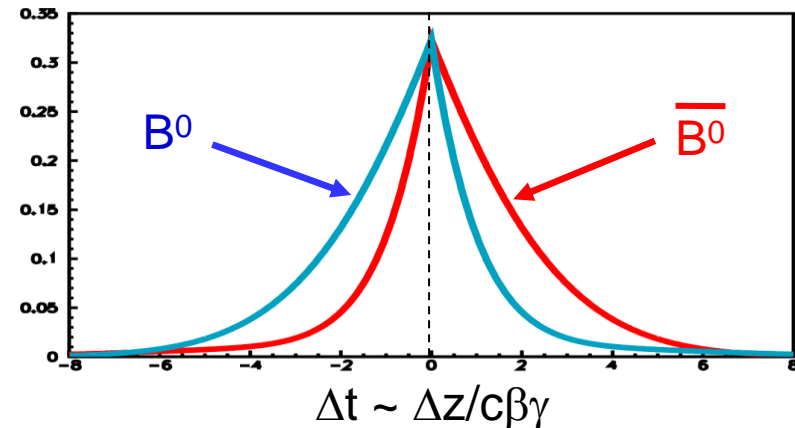
$$\phi_1 = \beta$$

S : mixing induced CPV

C : direct CPV (= -A)



measure position instead of time



Unitarity Triangle



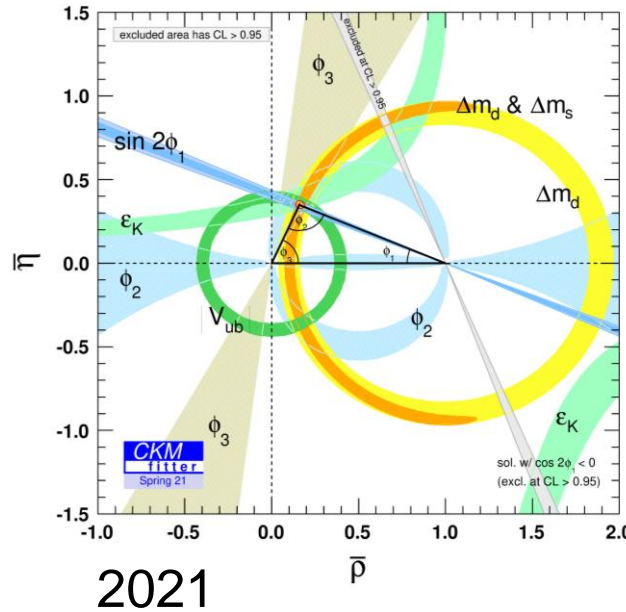
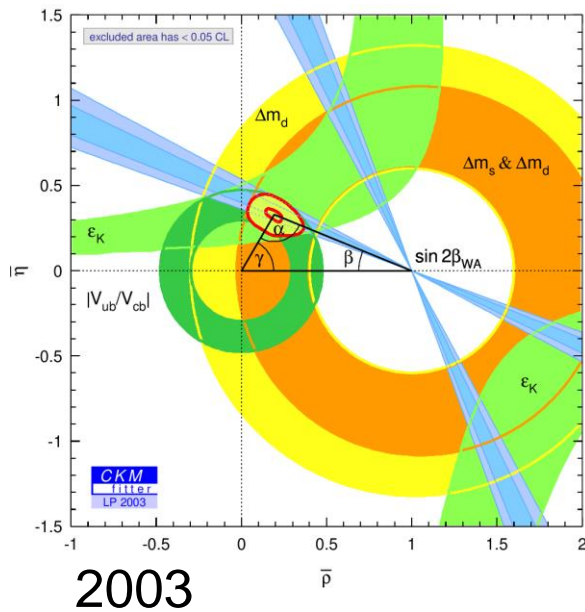
Observation CP violation in B mesons (2001): BaBar and Belle

$$\sin(2\beta) = 0.687 \pm 0.028 \pm 0.012 \quad (\text{BaBar [PRD79, 072009 (2009)])}$$

$$\sin(2\phi_1) = 0.667 \pm 0.023 \pm 0.012 \quad (\text{Belle [PRL108, 171802 (2012)])}$$



2008 Nobel Prize



?

$$\begin{aligned} \phi_1 &= \beta \\ \phi_2 &= \alpha \\ \phi_3 &= \gamma \end{aligned}$$

- Precise measurement of the Unitarity Triangle → Test of the SM
 - ✓ “Over-constrain” the triangle.
 - ✓ Still room of New Physics effects.

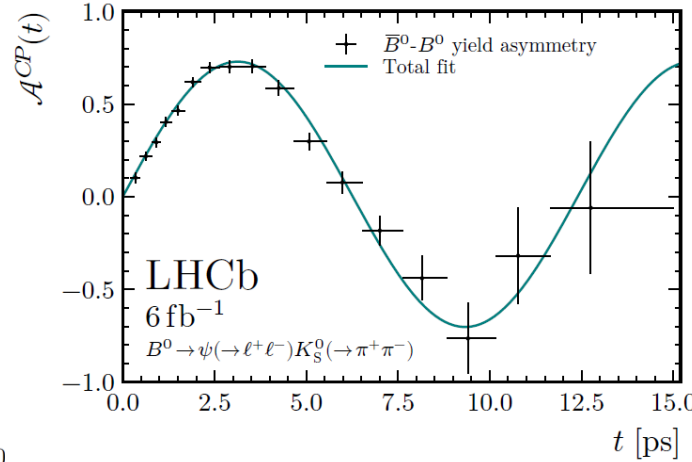
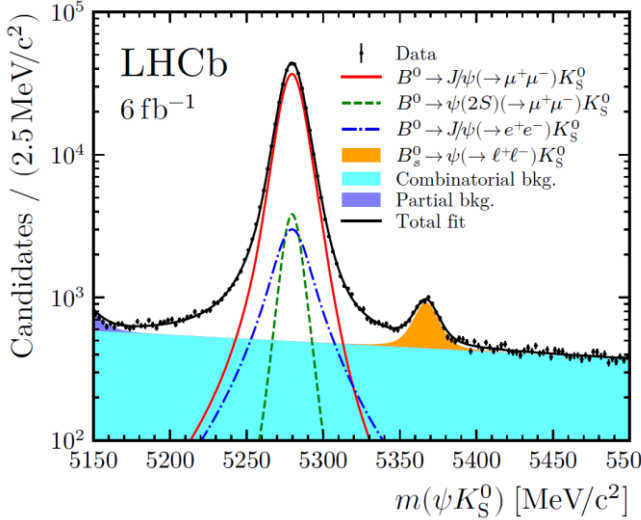


sin(2β) at LHCb

[arXiv:2309.09728]



- New result from LHCb using Run2 data (6 fb⁻¹).
- B → J/ψ (→ μ⁺μ⁻, e⁺e⁻) K_S, ψ(2S) (→ μ⁺μ⁻) K_S.



$$S(\psi K_S) = 0.717 \pm 0.013 \pm 0.008$$

$$C(\psi K_S) = 0.008 \pm 0.012 \pm 0.003$$

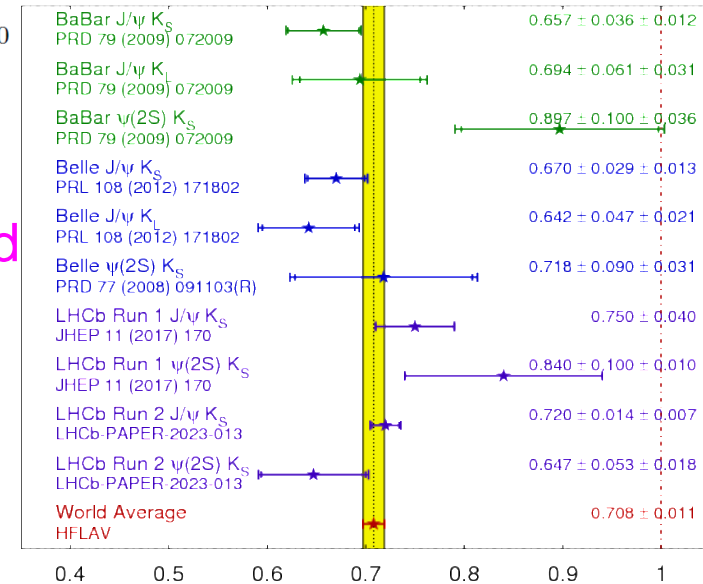
statistics dominated

Combined with Run2: $S(\psi K_S) = 0.724 \pm 0.014$

$$C(\psi K_S) = 0.004 \pm 0.012$$

Most precise result.

$\sin(2\beta) \equiv \sin(2\phi_1)$ **HFLAV**
Summer 2023
PRELIMINARY

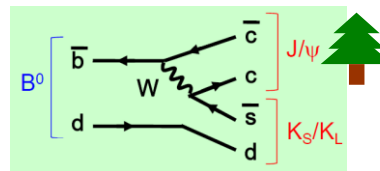


CPV in $B^0 \rightarrow \eta' K_S$ at Belle II

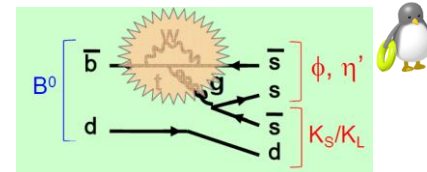


- $b \rightarrow s$ penguin process: sensitive to NP
- $S = -\xi \sin(2\phi_1)$ in the SM, but NP contribution can modify S.
- The theoretical uncertainty depends on the final states. $\eta' K^0$ is one of the cleanest modes.
- $B \rightarrow \eta' K_S$ from Belle II with 362 fb^{-1}

$b \rightarrow c$ ($B \rightarrow J/\psi K^0$)



$b \rightarrow s$ ($B \rightarrow \eta' K^0$)



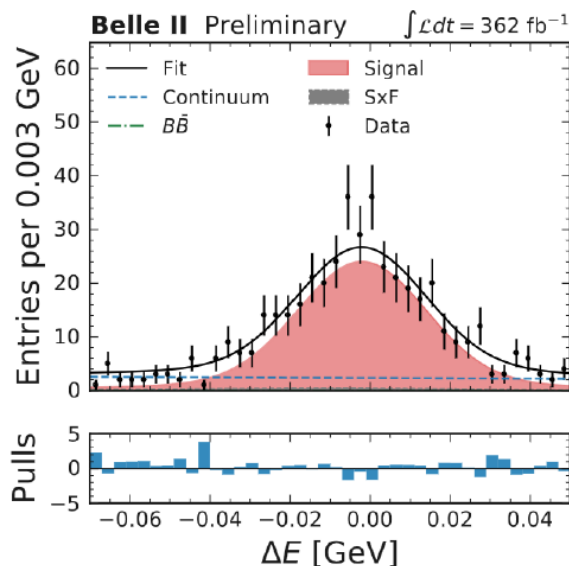
[EPS2023]

387 M BB

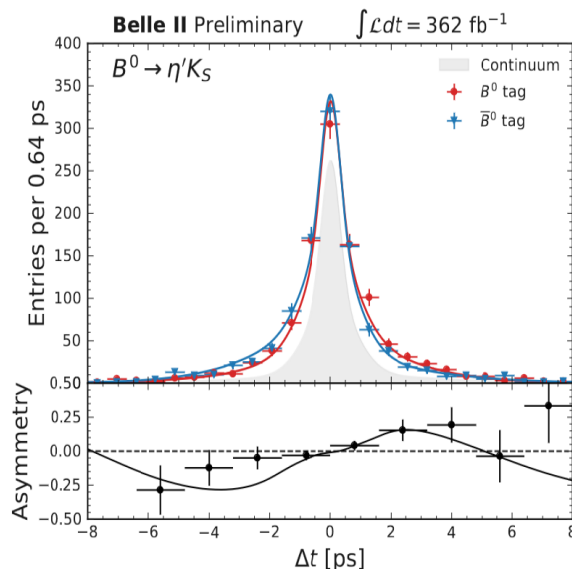
$$S = 0.67 \pm 0.10 \pm 0.04$$

$$C = -0.19 \pm 0.08 \pm 0.03$$

($B \rightarrow \eta' K_L$ or $\eta \rightarrow \pi^+ \pi^- \pi^0$ modes are not included yet)

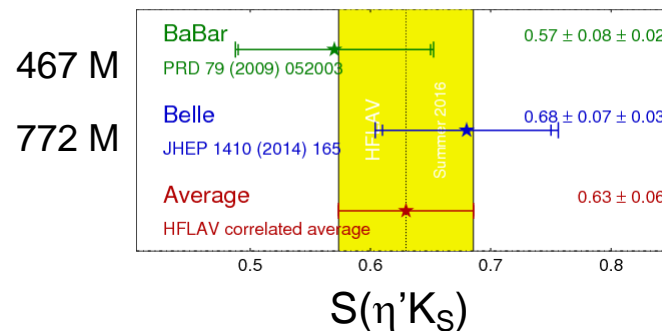


829 ± 35 signal events



$\eta' K^0 S_{CP}$

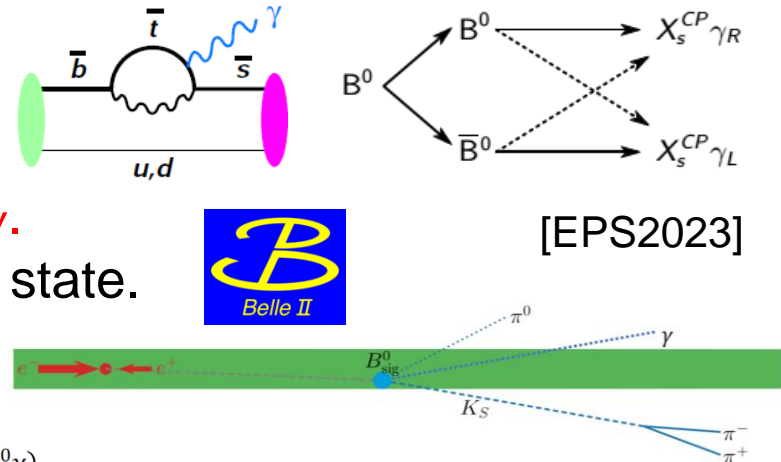
HFLAV Summer 2016



CPV in $B^0 \rightarrow K_S \pi^0 \gamma$ at Belle II



- SM electroweak is purely left-handed.
 - ✓ Photon from $b \rightarrow s \gamma$ is almost left-handed.
 - ✓ Right-handed current is a signature of NP.
- No mixed-induced CP violation in the SM in $b \rightarrow s \gamma$.
 - ✓ B^0 and \bar{B}^0 do not decay to the common final state.
 - ✓ (More correctly) $S \sim -2(m_s/m_b)\sin(2\phi_1)$

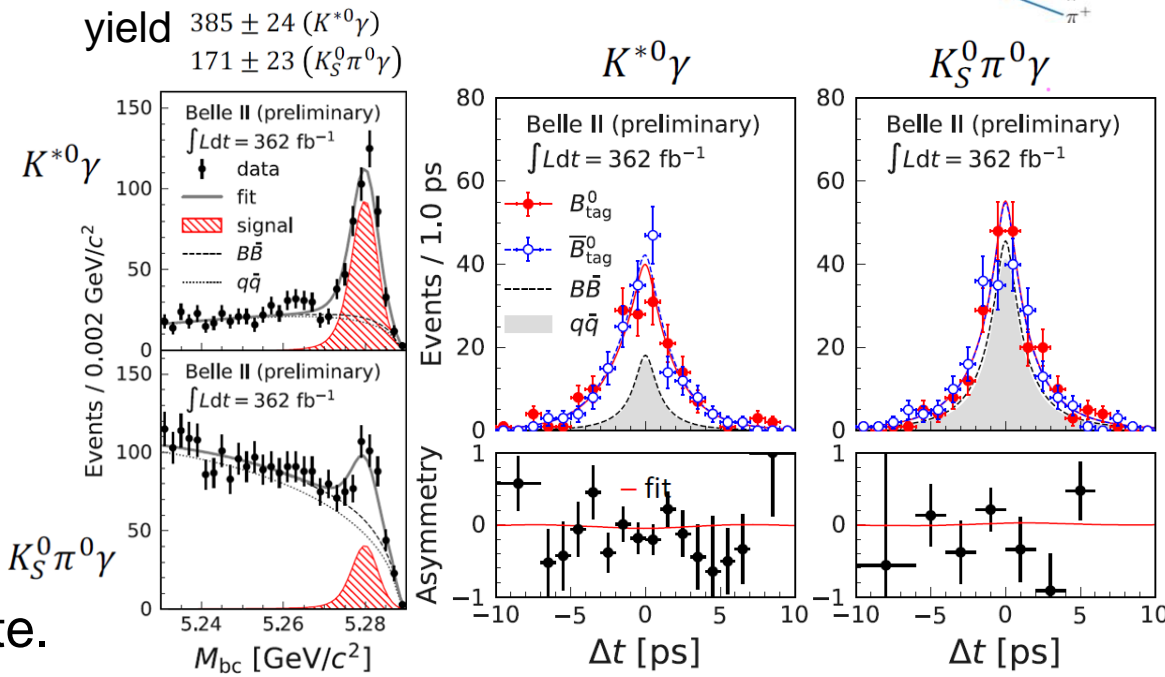


[EPS2023]

- New Belle II result with 362 fb^{-1} .
- B vertex from K_S only.
- Two $M(K\pi)$ regions: K^* [0.8, 1.0] GeV and the rest of [0.6, 1.8] GeV.

$S = 0.00^{+0.27}_{-0.26} \pm 0.03$	$K^{*0} \gamma$
$C = 0.10 \pm 0.13 \pm 0.03$	
• HFLAV: $S = -0.16 \pm 0.22$ $C = -0.04 \pm 0.14$	
$S = 0.04^{+0.45}_{-0.44} \pm 0.10$	$K_S^0 \pi^0 \gamma$
$C = -0.06 \pm 0.25 \pm 0.08$	
• Belle (2006): $S = 0.50 \pm 0.68$ $C = 0.20 \pm 0.39$	

Most precise measurements to date.



$B_s \rightarrow J/\psi \phi$

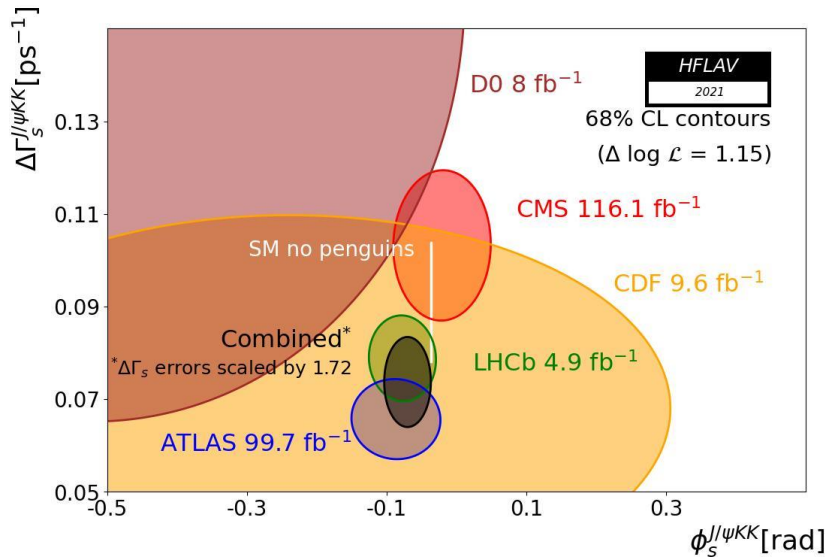
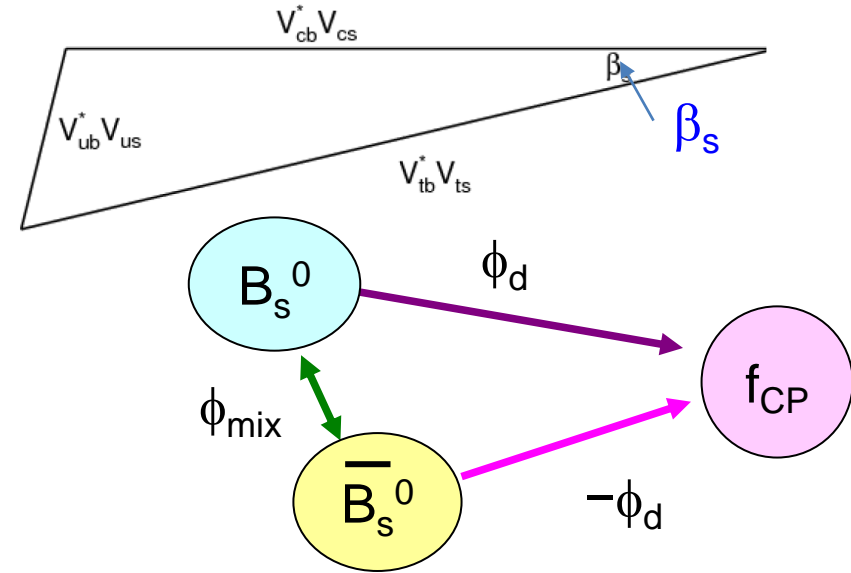
Another combination of the unitarity of the CKM matrix makes a squashed triangle.

$$V_{us} V_{ub}^* + V_{cs} V_{cb}^* + V_{ts} V_{tb}^* = 0$$

- β_s can be measured in mixing-induced CP violation in B_s decays like $B_s \rightarrow J/\psi \phi$.

$$\phi_s = \phi_{\text{mix}} - 2\phi_d = -2\beta_s \quad (\text{in SM})$$

$$\phi_s = -36.8^{+0.9}_{-0.6} \text{ mrad} \quad (\text{SM})$$



- Excellent time resolution ($<100\text{fs}$) necessary because of fast B_s oscillation
- Flavor tagging
- Two vectors in the final state.
 - ✓ Use angular distributions to extract the CP eigenstate.

HFLAV 2021

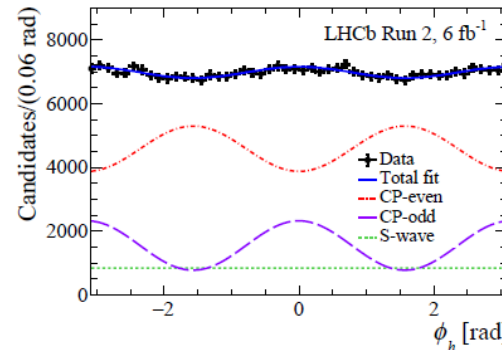
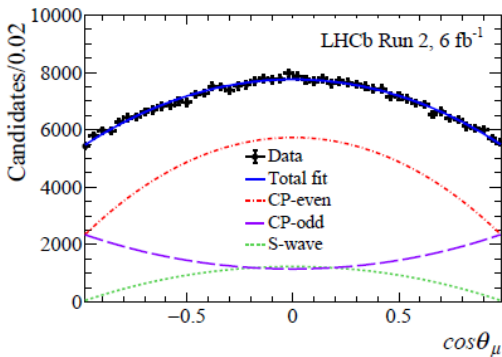
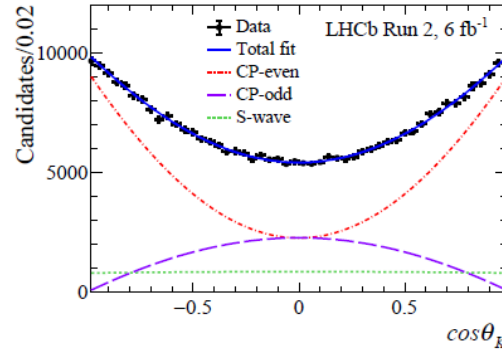
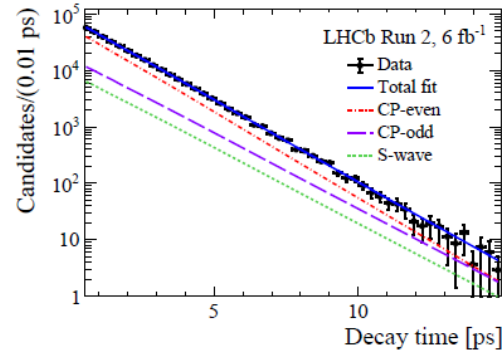
$B_s \rightarrow J/\psi \phi$ at LHCb



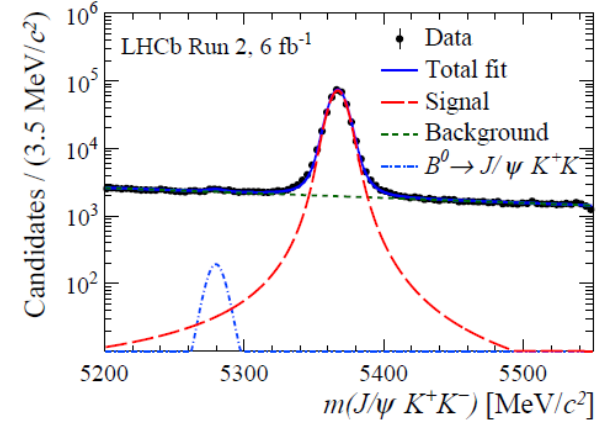
New result from LHCb using Run2 data (6 fb^{-1}).



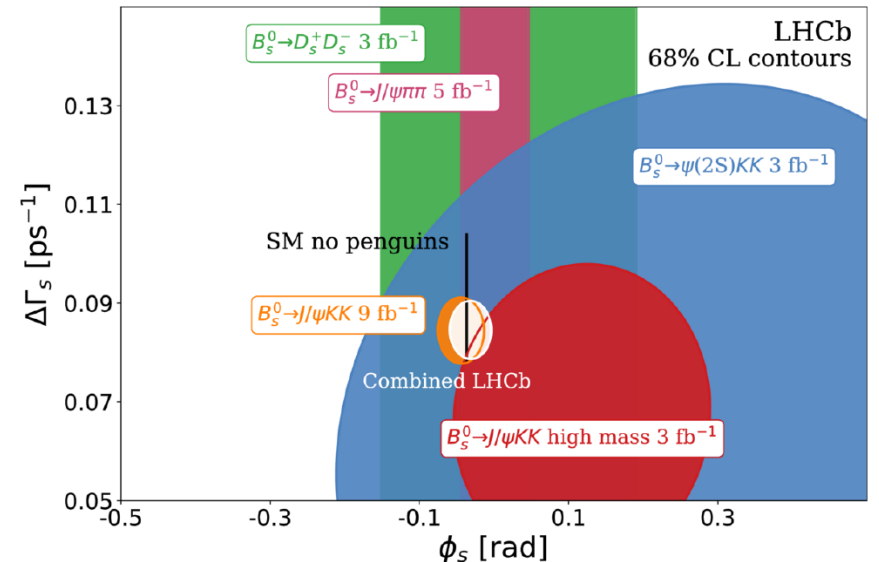
[arXiv:2309.09728]



- \blackcross Data
- Total fit
- - - CP-even
- · - · CP-odd
- · · S-wave

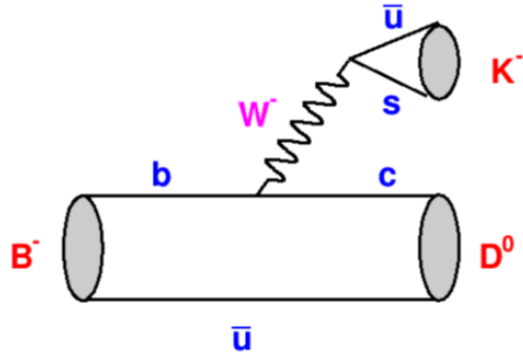


$$\begin{aligned} \phi_s &= -0.039 \pm 0.022 \pm 0.006 \text{ rad} \\ |\lambda| &= 1.001 \pm 0.011 \pm 0.005 \\ \Gamma_s - \Gamma_d &= -0.0056^{+0.0013}_{-0.0015} \pm 0.0014 \\ \Delta\Gamma_s &= 0.0845 \pm 0.0044 \pm 0.0024 \end{aligned}$$



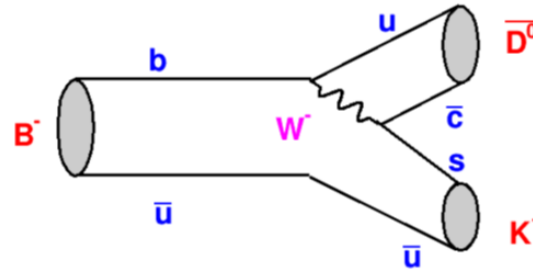
γ / ϕ_3

- γ / ϕ_3 can be measured using the interference $B \rightarrow D K$ and $B \rightarrow \bar{D} K$.
- ✓ Other modes like $B \rightarrow D K^*$, $B \rightarrow D \pi$ etc. are fine.



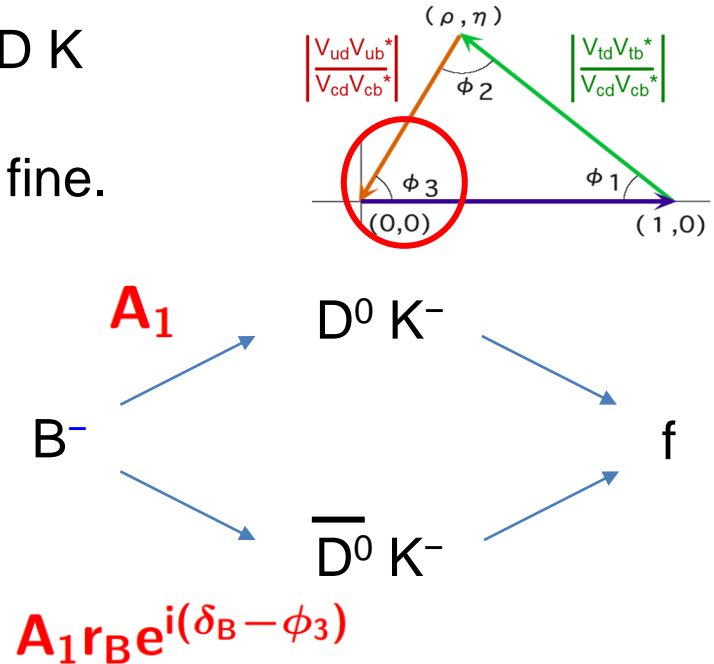
color favored

$$B^- \rightarrow D^0 K^- \approx V_{cb} V_{us}^* A_1$$



color suppressed

$$B^- \rightarrow \bar{D}^0 K^- \approx V_{ub} V_{cs}^* A_1 r_B e^{i(\delta_B - \phi_3)}$$



- Only tree contributions: theoretically clean.
- Several decay modes (final states) possible to extract γ / ϕ_3 .
- Amplitude ratio r_B and strong phase δ_B are mode-dependent.
- ✓ sensitivity depends on the decay modes.



- **GLW (Gronau-London-Wyler)** [PLB 253 (1991) 483, PLB 265 (1991) 172]
 - ✓ $B^\pm \rightarrow D_{CP}^0 K^\pm$
 - ✓ Use CP eigenstate of D meson.
- **ADS (Atwood-Dunietz-Soni)** [PRL 78, 3357 (1997), PRD 63. 036005 (2001)]
 - ✓ Enhancement of CP violation by using doubly Cabibbo suppressed decays.
- **BPGGSZ (Bondar-Poluektov-Giri-Grossmann-Soffer-Zupan)** [PRD 68. 054018 (2003)]
 - ✓ 3 (or multi-) body final state.
 - ✓ Different amplitude and strong phase in different region of Dalitz plot.
- **GLS (Grossmann-Ligeti-Soffer)** [PRD 67. 071301 (R) (2003)]
 - ✓ Singly Cabibbo suppressed D decay ($K_S K \pi$)

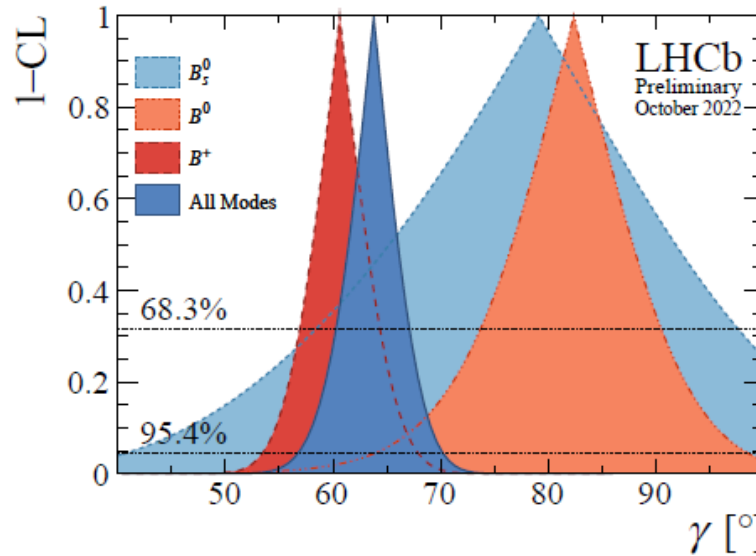
Note) D decay parameters (information on the strong phase) are necessary inputs from CLEO-c, BESIII.

Need improvements by BESIII for more precise measurement of γ / ϕ_3 .

LHCb Combined γ ($=\phi_3$)



B decay	D decay	Ref.	Dataset
$B^\pm \rightarrow Dh^\pm$	$D \rightarrow h^+h^-$	29	Run 1&2
$B^\pm \rightarrow Dh^\pm$	$D \rightarrow h^+\pi^-\pi^+\pi^-$	30	Run 1
$B^\pm \rightarrow Dh^\pm$	$D \rightarrow K^\pm\pi^+\pi^+\pi^-$	18	Run 1&2
$B^\pm \rightarrow Dh^\pm$	$D \rightarrow h^+h^-\pi^0$	19	Run 1&2
$B^\pm \rightarrow Dh^\pm$	$D \rightarrow K_S^0 h^+h^-$	31	Run 1&2
$B^\pm \rightarrow Dh^\pm$	$D \rightarrow K_S^0 K^\pm\pi^\mp$	32	Run 1&2
$B^\pm \rightarrow D^*h^\pm$	$D \rightarrow h^+h^-$	29	Run 1&2
$B^\pm \rightarrow DK^{*\pm}$	$D \rightarrow h^+h^-$	33	Run 1&2(*)
$B^\pm \rightarrow DK^{*\pm}$	$D \rightarrow h^+\pi^-\pi^+\pi^-$	33	Run 1&2(*)
$B^\pm \rightarrow Dh^\pm\pi^+\pi^-$	$D \rightarrow h^+h^-$	34	Run 1
$B^0 \rightarrow DK^{*0}$	$D \rightarrow h^+h^-$	35	Run 1&2(*)
$B^0 \rightarrow DK^{*0}$	$D \rightarrow h^+\pi^-\pi^+\pi^-$	35	Run 1&2(*)
$B^0 \rightarrow DK^{*0}$	$D \rightarrow K_S^0\pi^+\pi^-$	36	Run 1
$B^0 \rightarrow D^{\mp}\pi^\pm$	$D^+ \rightarrow K^-\pi^+\pi^+$	37	Run 1
$B_s^0 \rightarrow D_s^{\mp}K^\pm$	$D_s^+ \rightarrow h^+h^-\pi^+$	38	Run 1
$B_s^0 \rightarrow D_s^{\mp}K^\pm\pi^+\pi^-$	$D_s^+ \rightarrow h^+h^-\pi^+$	39	Run 1&2
D decay	Observable(s)	Ref.	Dataset
$D^0 \rightarrow h^+h^-$	ΔA_{CP}	24, 40, 41	Run 1&2
$D^0 \rightarrow K^+K^-$	$A_{CP}(K^+K^-)$	16, 24, 25	Run 2
$D^0 \rightarrow h^+h^-$	$y_{CP} - y_{CP}^{K^-\pi^+}$	42	Run 1
$D^0 \rightarrow h^+h^-$	$y_{CP} - y_{CP}^{K^-\pi^+}$	15	Run 2
$D^0 \rightarrow h^+h^-$	ΔY	43, 46	Run 1&2
$D^0 \rightarrow K^+\pi^-$ (Single Tag)	$R^\pm, (x^\pm)^2, y^\pm$	47	Run 1
$D^0 \rightarrow K^+\pi^-$ (Double Tag)	$R^\pm, (x^\pm)^2, y^\pm$	48	Run 1&2(*)
$D^0 \rightarrow K^\pm\pi^\mp\pi^+\pi^-$	$(x^2 + y^2)/4$	49	Run 1
$D^0 \rightarrow K_S^0\pi^+\pi^-$	x, y	50	Run 1
$D^0 \rightarrow K_S^0\pi^+\pi^-$	$x_{CP}, y_{CP}, \Delta x, \Delta y$	51	Run 1
$D^0 \rightarrow K_S^0\pi^+\pi^-$	$x_{CP}, y_{CP}, \Delta x, \Delta y$	52	Run 2
$D^0 \rightarrow K_S^0\pi^+\pi^-$ (μ^- tag)	$x_{CP}, y_{CP}, \Delta x, \Delta y$	17	Run 2



[LHCb-CONF-2022-003]

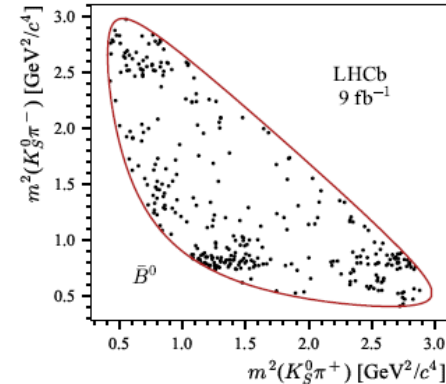


$$\gamma = (63.8^{+3.5}_{-3.7})^\circ$$

Global fit by CKM fitter

$$\gamma = (65.5^{+1.1}_{-2.7})^\circ$$

- Leading the γ measurement.
- Initial goal of 4° measurement achieved.



- A few more new results came this year (not included above)

✓ e.g., $B^0 \rightarrow D K^*$ with $D \rightarrow K_S h^+h^-$ [arXiv:2309.05514].

$$\gamma = (49^{+22}_{-19})^\circ$$

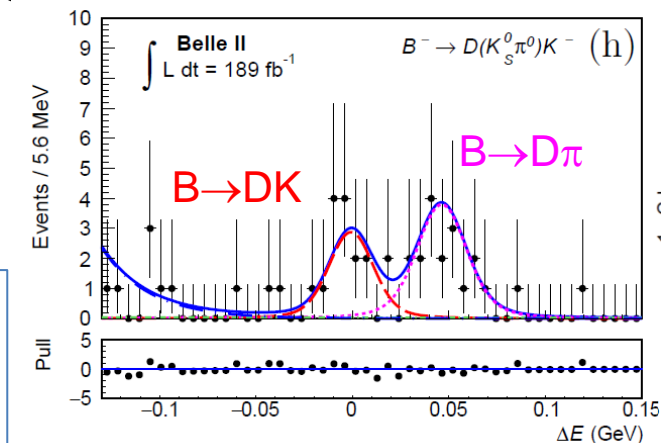
Belle + Belle II Combined ϕ_3 ($=\gamma$)



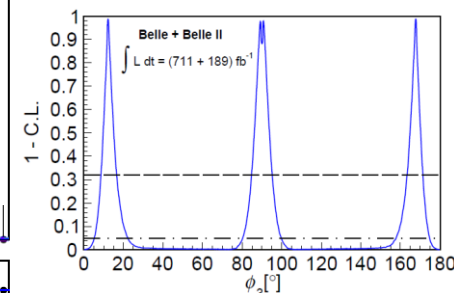
Belle II: new results with Belle + Belle II combined analysis.



- Example: $B^\pm \rightarrow D_{CP} K^\pm$ with $D_{CP} \rightarrow K^+ K^-, K_S^0 \pi^0$ (GLW method)
- CP-odd $K_S^0 \pi^0$: unique to Belle (II)
- Belle 711 fb^{-1} + Belle II 189 fb^{-1}
- Some constraint on ϕ_3 .
Combined with other results.



[arXiv:2308.05048]



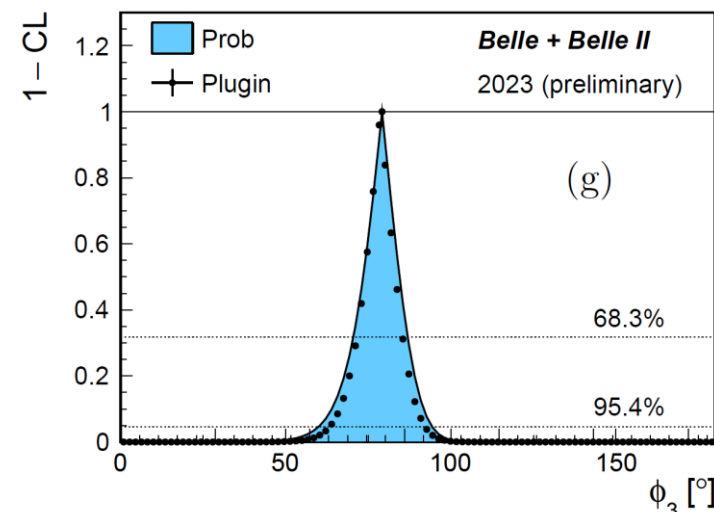
B decay	D decay	Method	Data set (Belle + Belle II)[fb^{-1}]
$B^+ \rightarrow Dh^+$	$D \rightarrow K_S^0 h^- h^+$	BPGGSZ	711 + 128
$B^+ \rightarrow Dh^+$	$D \rightarrow K_S^0 \pi^- \pi^+ \pi^0$	BPGGSZ	711 + 0
$B^+ \rightarrow Dh^+$	$D \rightarrow K_S^0 \pi^0, K^- K^+$	GLW	711 + 189
$B^+ \rightarrow Dh^+$	$D \rightarrow K^+ \pi^-, K^+ \pi^- \pi^0$	ADS	711 + 0
$B^+ \rightarrow Dh^+$	$D \rightarrow K_S^0 K^- \pi^+$	GLS	711 + 362
$B^+ \rightarrow D^* K^+$	$D \rightarrow K_S^0 \pi^- \pi^+$	BPGGSZ	605 + 0
$B^+ \rightarrow D^* K^+$	$D \rightarrow K_S^0 \pi^0, K_S^0 \phi, K_S^0 \omega,$ $K^- K^+, \pi^- \pi^+$	GLW	210 + 0

[CKM2023]

Likelihood fit with 60 input observables and 16 auxiliary inputs (external D-decay parameters).

$$\phi_3 = (78.6 \pm 7.3)^\circ \quad \text{Consistent with WA.}$$

Prospect: 1.5° at 50 ab^{-1} [arXiv:2203.11349]



Other Measurements



Many topics cannot be covered in this talk

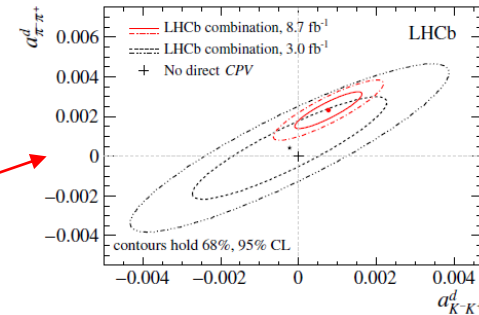
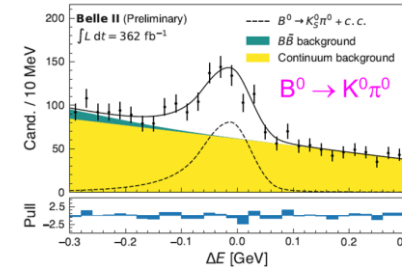
- B_d and B_s mixing
 - ✓ Measurements by LHCb
- $|V_{ub}|$ and $|V_{cb}|$ from semi-leptonic B decays
 - ✓ Recent progress in Belle, Belle II
- Measurement of ϕ_2 / α
- ϕ_s from loop diagram

•
and

- Direct CP violations in charmless B decays
 - ✓ $B \rightarrow K\pi$ sum rule $I_{K\pi}$
- CP asymmetry in charm
 - ✓ $A_{CP}(D^0 \rightarrow K^- K^+)$
 - ✓ A_{CP} in multi-body D^0 decays
-

[arXiv:2310.06381 (accepted at PRD)]

$$I_{K\pi} = -0.03 \pm 0.13 \pm 0.04$$



[PRL 131, 091802]



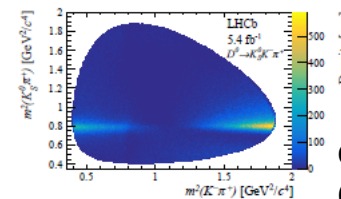
[arXiv:2310.19397]

$$D^0 \rightarrow K_S^0 K^\pm \pi^\mp$$



[JHEP09(2023)129]

$$D^0 \rightarrow \pi^- \pi^+ \pi^0$$



consistent with CP symmetry

Prospects

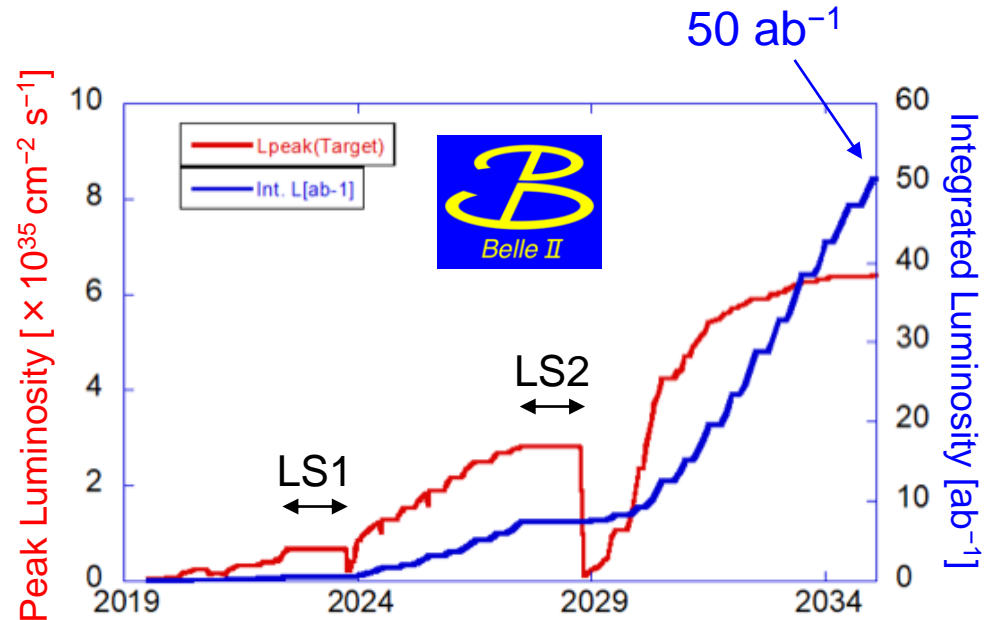


LHCb



Further improvements (higher precisions, studies of new modes, observables) are expected with more than one order larger data samples.

- LHCb ($9 \text{ fb}^{-1} \rightarrow 300 \text{ fb}^{-1}$)
 - ✓ precision of γ : $4^\circ \rightarrow 0.35^\circ$
 - ✓ precision of ϕ_s (from $B_s \rightarrow J/\psi \phi$): $22 \text{ mrad} \rightarrow 4 \text{ mrad}$
- Belle II ($1 \text{ ab}^{-1} \rightarrow 50 \text{ ab}^{-1}$)
 - ✓ precision of $S(\eta'K_S)$: $0.08 \rightarrow 0.015$



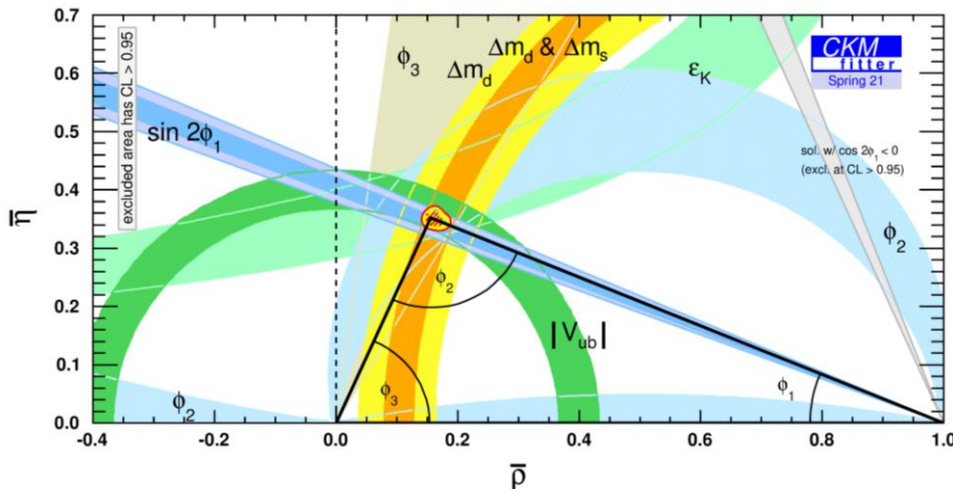
[LHCb-PUB-2022-012, arXiv:2203.11349]

Summary and Conclusion

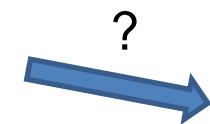
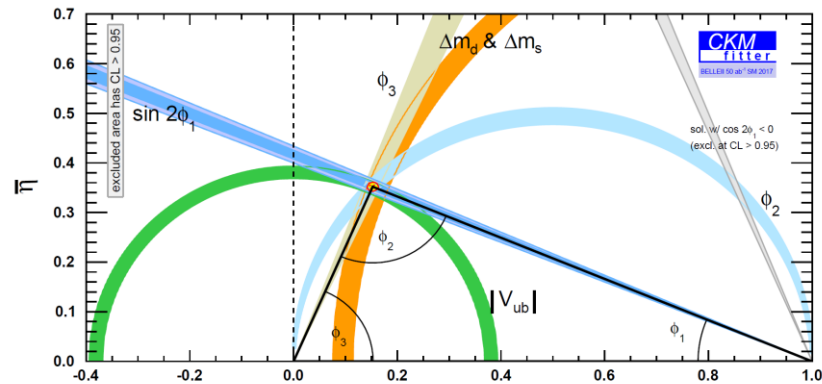
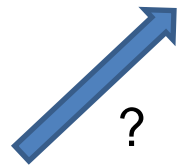


- Precise measurements of Unitarity Triangle provides an interesting test for New Physics.
- LHCb has been improving the measurements.
- Belle II started and has joined the game.
 - ✓ Unique measurements for some modes.
- Consistent with the SM or not ?

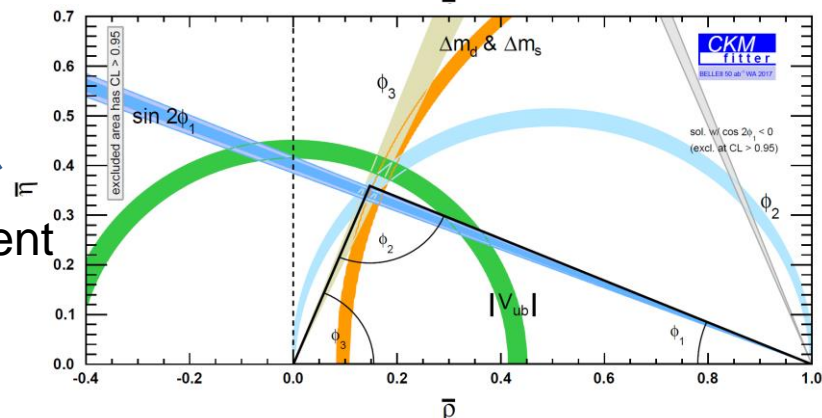
[PTEP (2019) 123C01
(arXiv:1808.10567)]



consistent



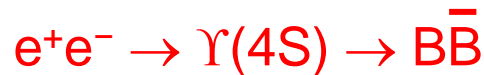
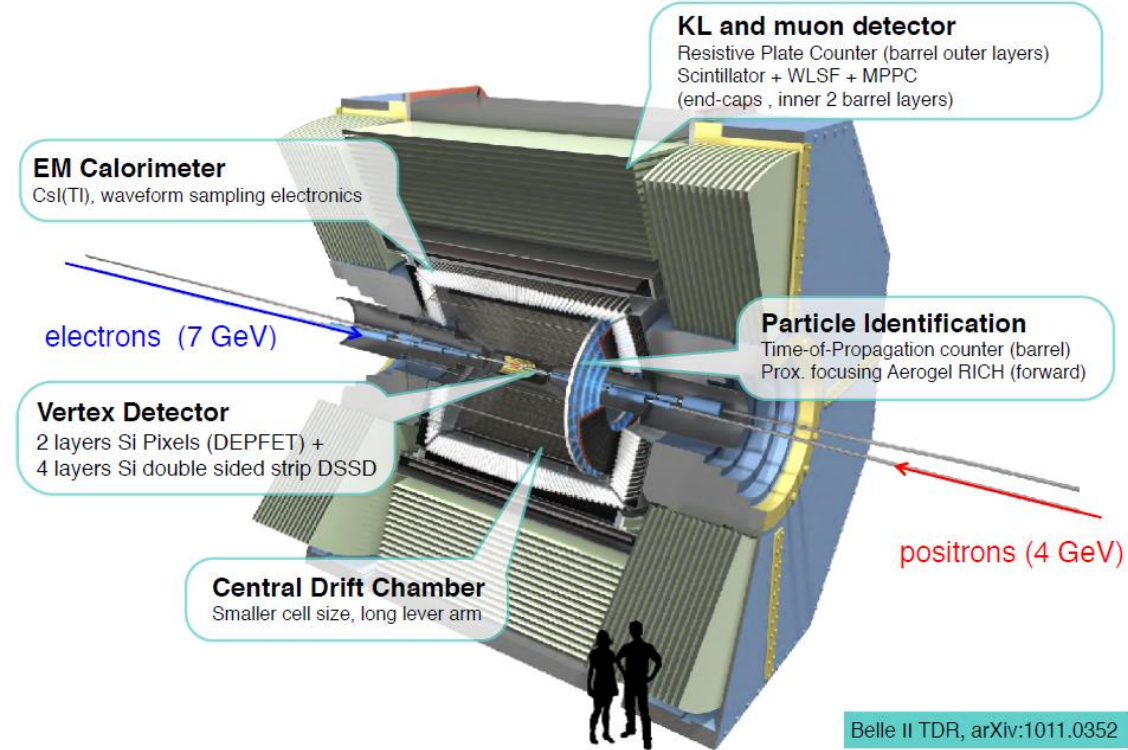
inconsistent





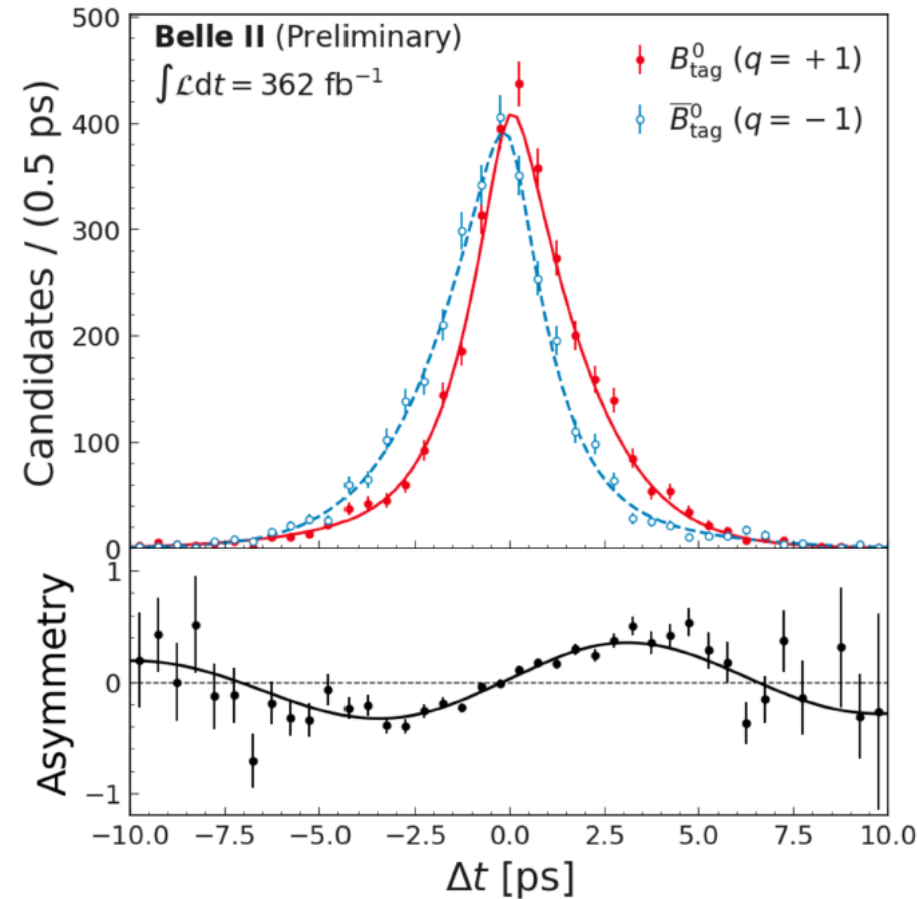
Backup

SuperKEKB and Belle II



- Belle II experiment at KEK: flavor physics experiment, successor of Belle.
- SuperKEKB asymmetric electron-positron collider: 4 GeV e^+ + 7 GeV e^- .
- Nano beam scheme to achieve high luminosity.
- General purpose Belle II detector: 4π coverage
 - ✓ Key components: vertex detector, particle identification.

CPV in $B^0 \rightarrow J/\psi K_S$ at Belle II



- ◆ τ_{B^0} and Δm_d ([PRD107\(2023\)9,L091102](#))
 - Measured in $B^0 \rightarrow D^{(*)-} \pi^+$
 - $\tau_{B^0} = 1.499 \pm 0.013 \pm 0.008 \text{ ps}$
 - $\Delta m_d = 0.516 \pm 0.008 \pm 0.005 \text{ ps}^{-1}$
- ◆ S and C fit
 - Δt resolution considered in PDF
 - remove background from the fit ([sFit](#))
 - $S = 0.724 \pm 0.035 \pm 0.014$
 - $C = 0.035 \pm 0.026 \pm 0.012$
 - HFLAV: $S = 0.695 \pm 0.019$ $C = 0.000 \pm 0.020$
 - LHCb: $S = 0.716 \pm 0.015$ $C = 0.012 \pm 0.012$

GFlaT reduces statistical uncertainty by $\sim 8\%$

GFlaT: GNN Flavor Tagger



◆ Motivation

□ Category-based BDT does not consider relations b/w particles

- e.g., $B^0 \rightarrow K^- X$ fakes $\bar{B}^0 \rightarrow D^0/D^+ \rightarrow K^-$ chain

◆ Graph Neural Network

□ Node = particle, Edge = relation

→ Utilize characteristics of relations

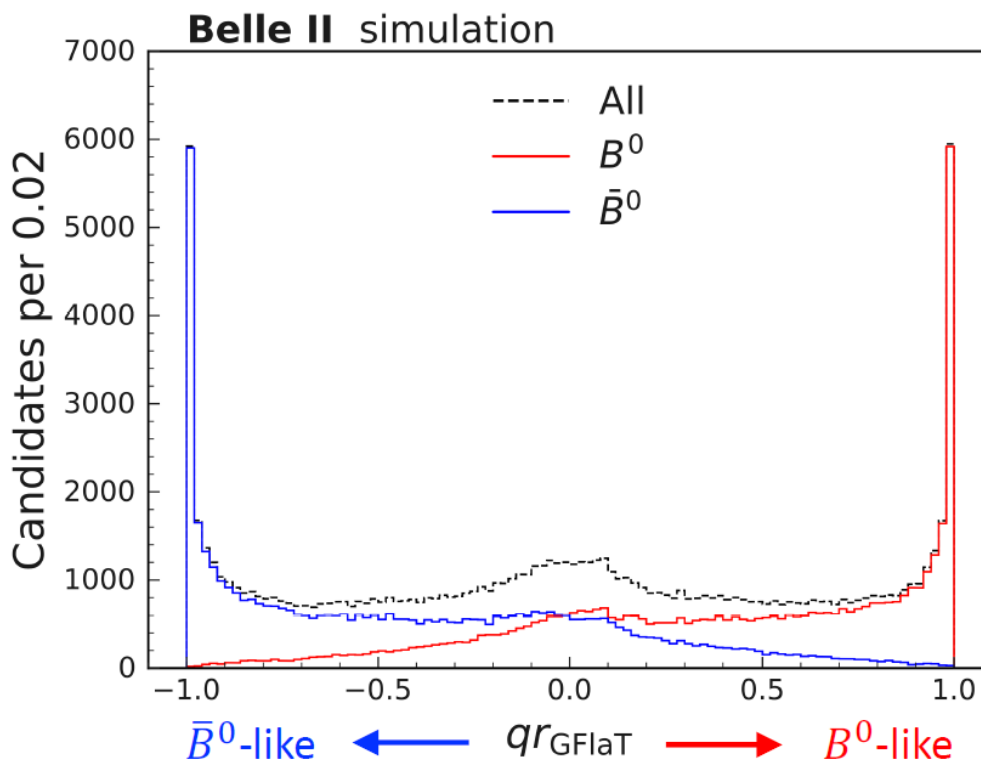
- e.g., prompt/secondary K^- can be distinguished

□ Effective tagging efficiency in data:

$(31.68 \pm 0.45 \pm 0.41)\%$

→ $(37.40 \pm 0.43 \pm 0.34)\%$ 18% gain

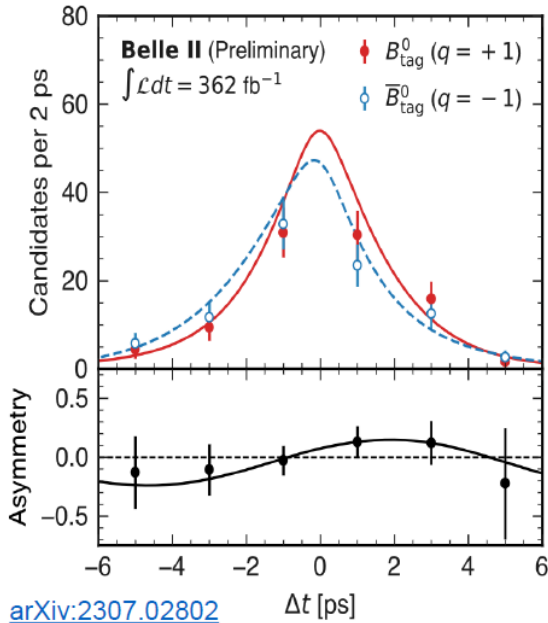
- c.f. $28.8 \pm 0.6\%$ in Belle



CPV in $b \rightarrow s$ at Belle II



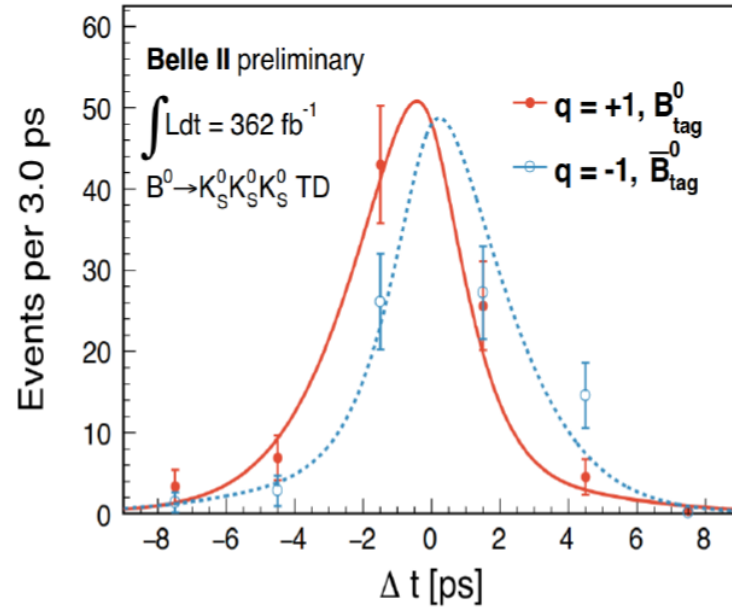
$B^0 \rightarrow \varphi K_S$



$$C_{CP} = -0.31 \pm 0.20 \pm 0.05$$

$$S_{CP} = 0.54 \pm 0.26^{+0.06}_{-0.08}$$

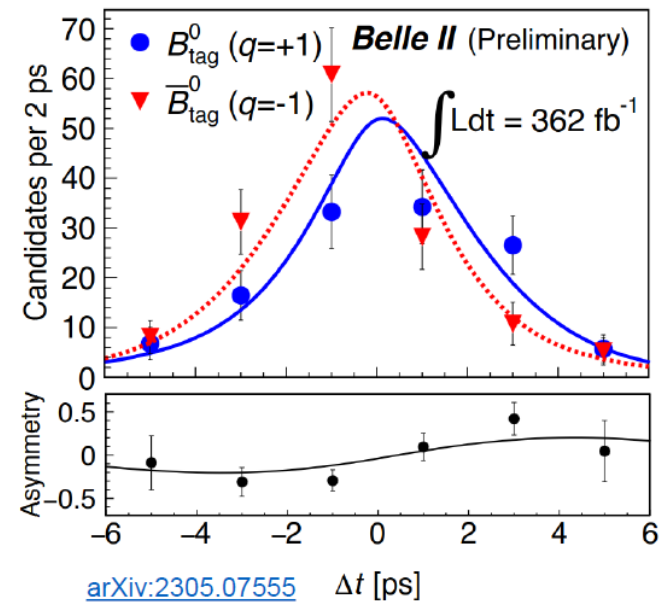
$B^0 \rightarrow K_S K_S K_S$



$$C_{CP} = -0.07 \pm 0.20 \pm 0.05$$

$$S_{CP} = -1.37^{+0.35}_{-0.45} \pm 0.03$$

$B^0 \rightarrow K_S \pi^0$



$$C_{CP} = -0.04 \pm 0.15 \pm 0.05$$

$$S_{CP} = 0.75^{+0.20}_{-0.23} \pm 0.04$$

HFLAV: $C_{CP} = 0.01 \pm 0.14$ $S_{CP} = 0.74^{+0.11}_{-0.13}$

HFLAV: $C_{CP} = -0.15 \pm 0.12$ $S_{CP} = -0.83 \pm 0.17$ HFLAV: $C_{CP} = 0.01 \pm 0.10$ $S_{CP} = 0.57 \pm 0.17$

Belle + Belle II Combined ϕ_3 ($=\gamma$)



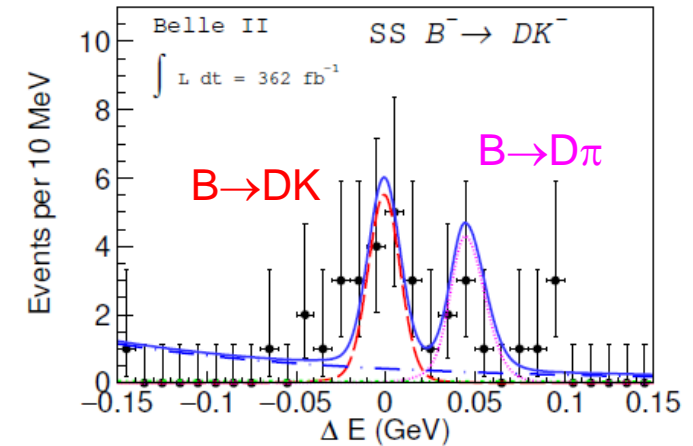
- $B^\pm \rightarrow DK^\pm, D\pi^\pm$ with $D \rightarrow K_S K^\pm \pi^\mp$ (GLS method)
- Belle 711 fb^{-1} + Belle II 362 fb^{-1}
- The results alone do not determine ϕ_3 ,
Combined with other results.



[JHEP09(2023)146]

Table 2. The auxiliary input observables and their values used in the ϕ_3 combination.

Decay	Observable	Value	Source	Reference
$D \rightarrow K^+ \pi^-$	$R_D^{K\pi}$	$(3.44 \pm 0.02) \times 10^{-3}$	HFLAV	[5]
	$\delta_D^{K\pi}$	$(191.7 \pm 3.7)^\circ$		
	$r_D^{K\pi} \cos(\delta_D^{K\pi})$	-0.0562 ± 0.0081	BESIII	[27]
	$r_D^{K\pi} \sin(\delta_D^{K\pi})$	-0.011 ± 0.012		
$D \rightarrow K^+ \pi^- \pi^0$	$r_D^{K\pi\pi^0}$	0.0447 ± 0.0012	CLEO + LHCb	[28]
	$R_D^{K\pi\pi^0}$	0.81 ± 0.06		
	$\delta_D^{K\pi\pi^0}$	$(198 \pm 15)^\circ$		
	$r_D^{K\pi\pi^0}$	0.0440 ± 0.0011	BESIII	[29]
	$R_D^{K\pi\pi^0}$	0.78 ± 0.04		
	$\delta_D^{K\pi\pi^0}$	$(196 \pm 15)^\circ$		
$D \rightarrow K_S^0 K^- \pi^+$	$(r_D^{K_S^0 K^- \pi^+})^2$	0.356 ± 0.034	CLEO	[30]
	$\kappa_D^{K_S^0 K^- \pi^+}$	0.94 ± 0.12		
	$\delta_D^{K_S^0 K^- \pi^+}$	$(-16.6 \pm 18.4)^\circ$	LHCb	[31]
	$(r_D^{K_S^0 K^- \pi^+})^2$	0.370 ± 0.003		
$B^+ \rightarrow Dh^+$	R_{GLS}	0.0789 ± 0.0027	PDG	[32]



$$\begin{aligned}
 A_{\text{SS}}^{DK} &= 0.055 \pm 0.119 \pm 0.020, \\
 A_{\text{OS}}^{DK} &= 0.231 \pm 0.184 \pm 0.014, \\
 A_{\text{SS}}^{D\pi} &= 0.046 \pm 0.029 \pm 0.016, \\
 A_{\text{OS}}^{D\pi} &= 0.009 \pm 0.046 \pm 0.009, \\
 R_{\text{SS}}^{DK/D\pi} &= 0.093 \pm 0.012 \pm 0.005, \\
 R_{\text{OS}}^{DK/D\pi} &= 0.103 \pm 0.020 \pm 0.006, \\
 R_{\text{SS/OS}}^{D\pi} &= 2.412 \pm 0.132 \pm 0.019,
 \end{aligned}$$

B → Kπ (sum-rule)



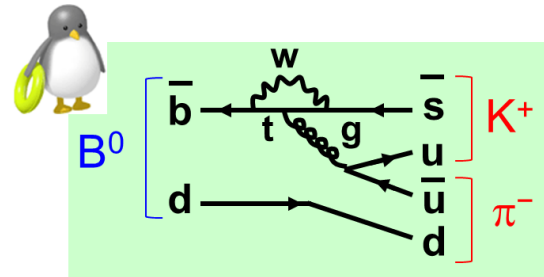
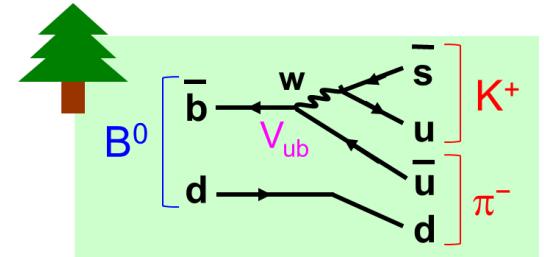
B → Kπ

- Rare decay, but relatively high branching fraction ($\sim 10^{-5}$)
- Tree diagram (with V_{ub}) + penguin diagram
 - ✓ Direct CP violation is possible (observed)
- The sum-rule provides precise prediction of the relation of the branching fractions and A_{CP} .

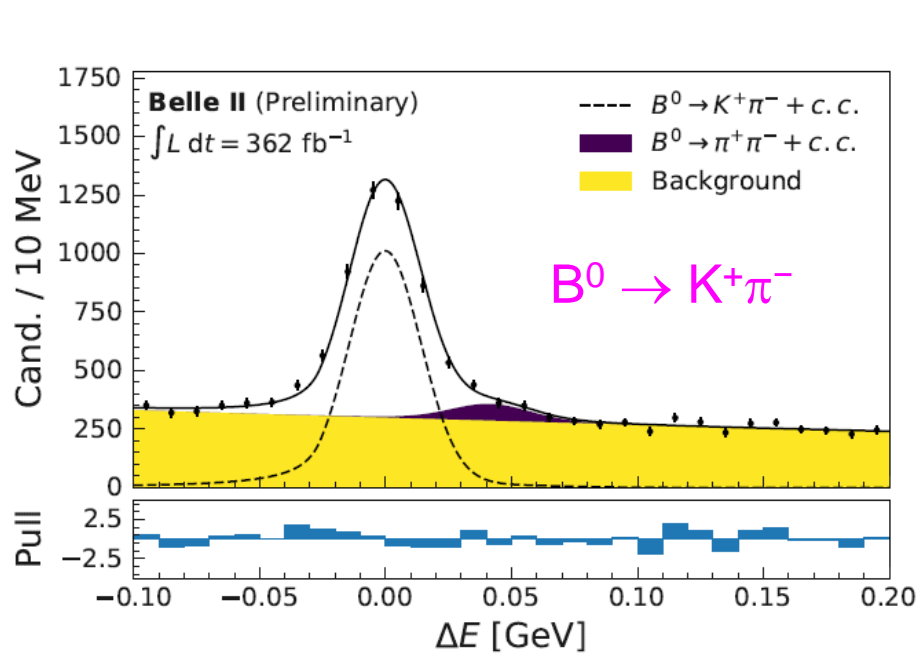
[M.Gronau, PLB627 (2005) 82]

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

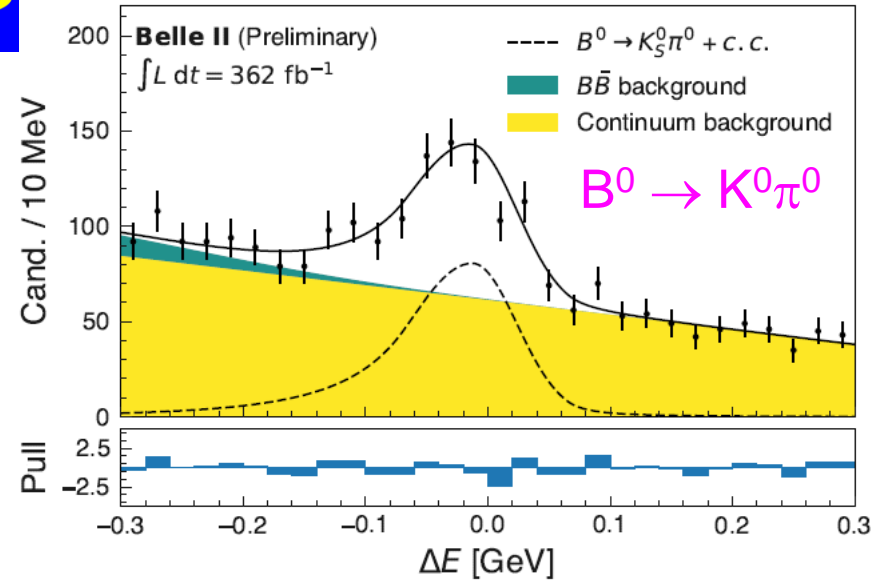
- $I_{K\pi}$ is predicted to be 0 within 1%
- Belle II can measure all the observables.



B \rightarrow K π (sum-rule) from Belle II



[arXiv:2310.06381 (accepted at PRD)]



$$B(B^0 \rightarrow K^+ \pi^-) = (20.67 \pm 0.37 \pm 0.62) \times 10^{-6}$$

$$A_{CP}(B^0 \rightarrow K^+ \pi^-) = -0.072 \pm 0.019 \pm 0.007$$

$$B(B^0 \rightarrow K^0 \pi^0) = (10.40 \pm 0.66 \pm 0.60) \times 10^{-6}$$

$$A_{CP}(B^0 \rightarrow K^0 \pi^0) = -0.06 \pm 0.15 \pm 0.04$$

from the time-integrated analysis. This is combined with the time-dependent analysis.

$$I_{K\pi} = -0.03 \pm 0.13 \pm 0.04$$

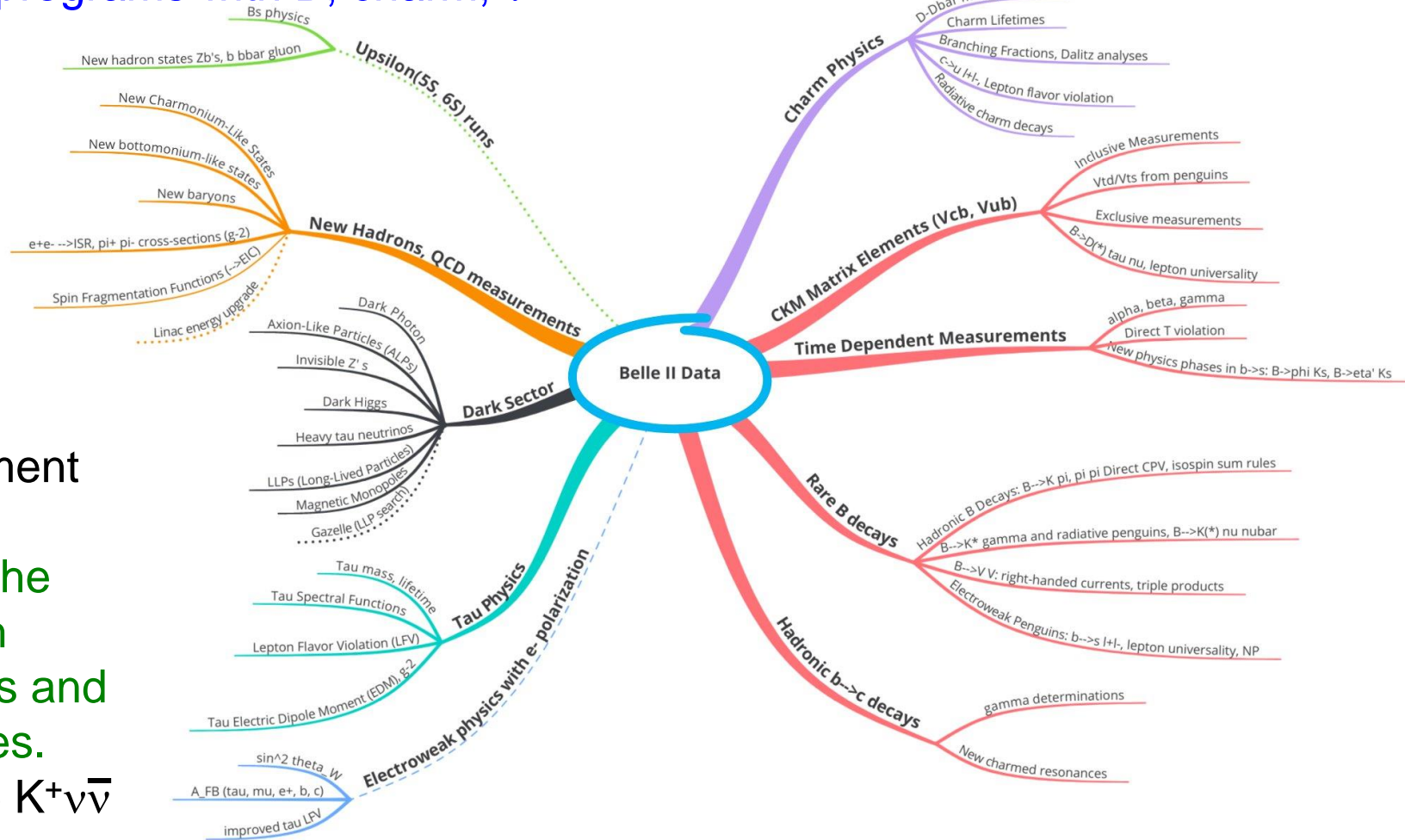
- Consistent with the SM prediction (null).
- Competitive with world average (-0.13 ± 0.11)

even with smaller dataset than Belle

Physics at Belle II



- Intensity frontier experiment: Search for New Physics with precise measurements.
- Rich physics programs with B, charm, τ .



• Clean environment (e^+e^- collider) : advantage for the final states with neutral particles and missing particles.

✓ e.g. $B^+ \rightarrow K^+ \nu \bar{\nu}$

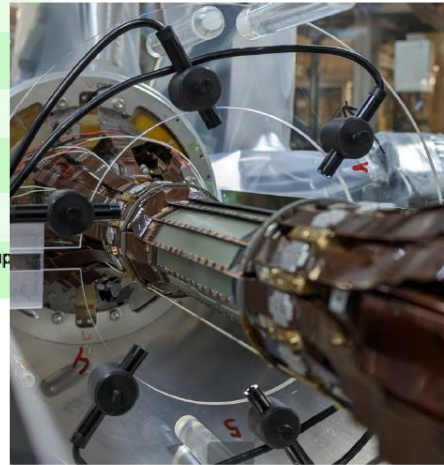
LS1 @ SuperKEKB, Belle II



PXD/SVD	PXD commissioning plan in KEK, and VXD reinstallation. SVD 3/6-mixed mode.
CDC	Improvement in gas circulation and monitoring
TOP	TOP MCP-PMT replacement
ECL	Improvement in pedestal correction Gain adjustment on ShaperDSP
KLM	BB2 efficiency recovery Reinforcement of monitoring system
TRG	Optimization of trigger veto. TOPTRG
DAQ	PCIe40 long-term stability test with realistic high-occupancy data
Background	Additional neutron shields
MDI	Installation of additional loss monitors and speed-up abort signal

2022-2023

PXD2 at KEK since March



TOP MCP-PMT replacement work



CDC FE reinstallation work



VXD extraction in May



SVD standalone commissioning



but also DAQ upgrade,
KLM work,



LINAC

- e- beam
 - Laser system has worked fine without any significant trouble.
 - DOE was installed also at 2nd laser line in the last summer maintenance, and it has worked fine.
 - In the run 2022a/b, bunch charge of 2 nC can be kept with bunch charge feedback.
 - 5 nC from gun was demonstrated. Further beam study is on-going during LS1.
 - New DOE with large area improve energy spread and emittance until HER injection.
 - BTe-ECS is planned to install at FY2024
- e+ beam
 - The new FC is working fine.
 - Reached bunch charge of 3.5 nC at BT end (final design 4 nC).
- Upgrade work during LS1
 - Pulsed Quads (x8) at J-ARC for the simultaneous dedicated matching of HER/LER injection beam
 - Pulsed Quads (x4) at Sector1, 2 for low beta optics of HER injection beam
 - New accelerating structure
 - Replacement of air conditioners at SectorA, B (in the accelerator tunnel)
 - Fast kicker for 2nd bunch orbit correction
- Issues
 - Emittance growth at end of BT2 for both of e- and e+ beam (BT report, Injection report)
 - Low e- injection efficiency of 2nd bunch
 - Increase the e- bunch charge while keeping small emittance

MR

- Many upgrade & maintenance works are progressed during LS1.
 - LS1 started in July 2022 and will end in November 2023.
 - Next beam operation is scheduled to restart in December 2023.
- Progress of “IR works” & “NLC construction” were reported.
 - And also, damaged collimator heads were replaced with new ones.
 - Most planed works will be completed by October 2023.
 - Beam operation will resumed from December 2023.
- Sudden Beam Loss (SBL) is one of the concerned issues to be solved.
 - Frequently, the beam suddenly disappears within few turns just before the abort.
 - The cause of SBL is still unknown. (Several candidates for the cause are considered.)
 - Continuation of investigation or study of SBL is needed to avoid it.