Quark Flavor Physics Experiments: CP Violation

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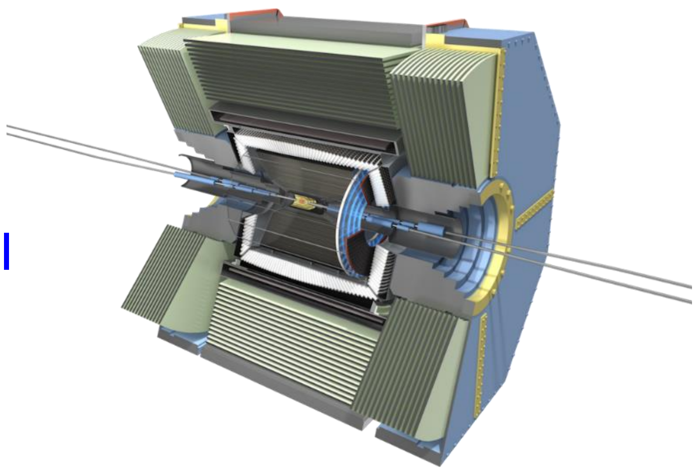
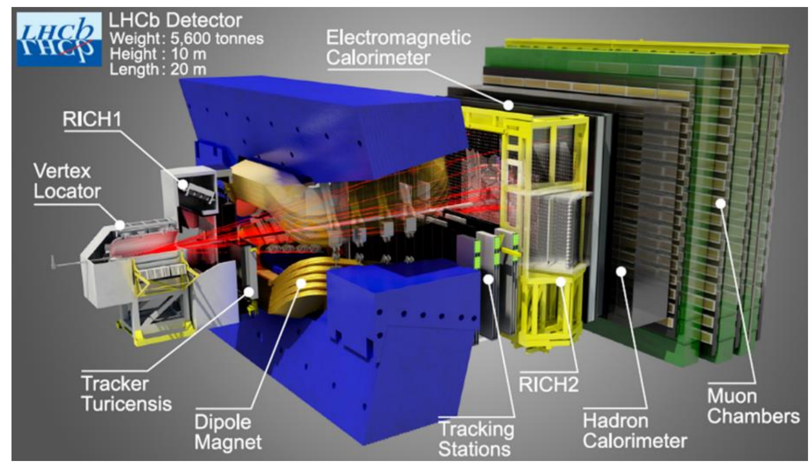
Belle II

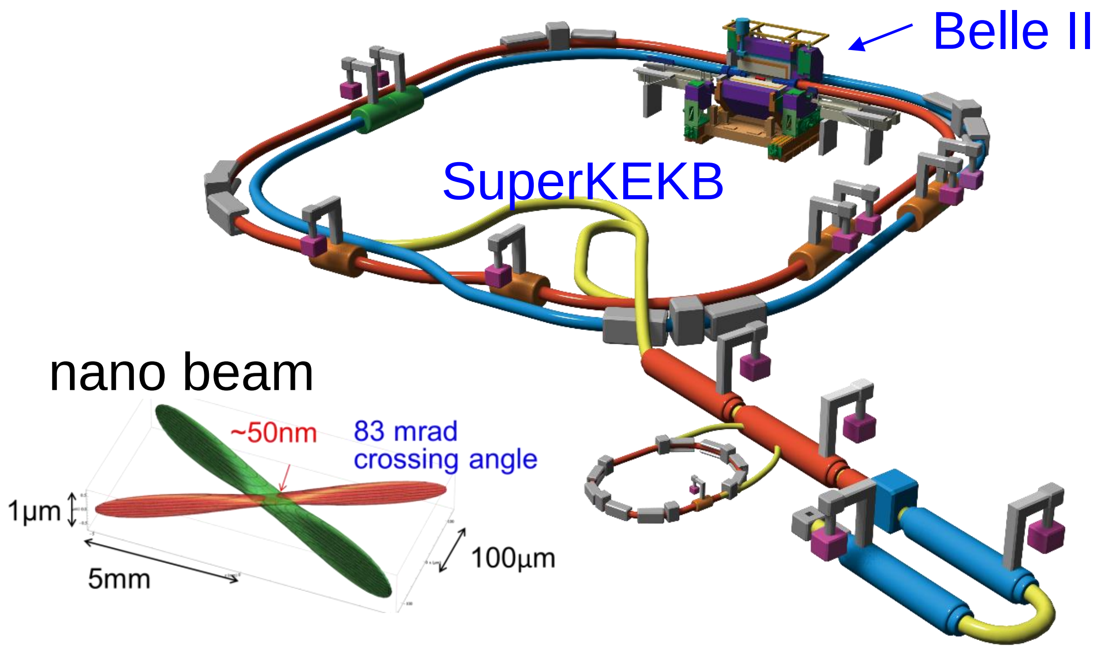


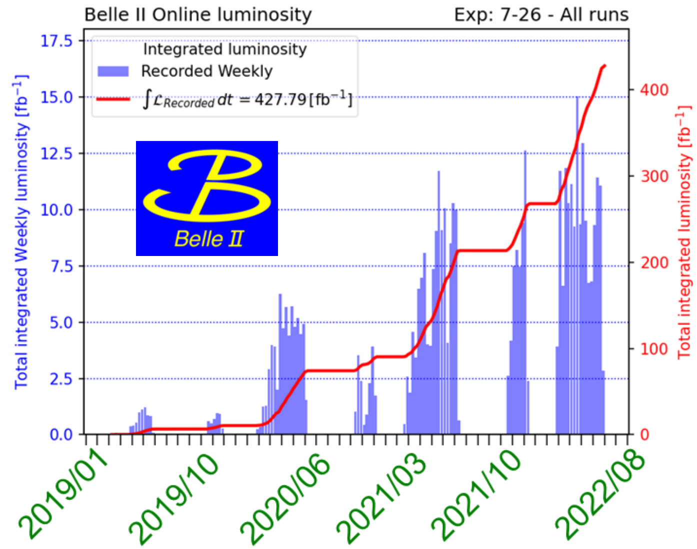
LHCb



- 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.

- Luminosity 4.7×10^{34} cm^{-2} s^{-1} achieved (Jun. 2022):
  - ✓ World record (~ ×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} .

- 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.

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

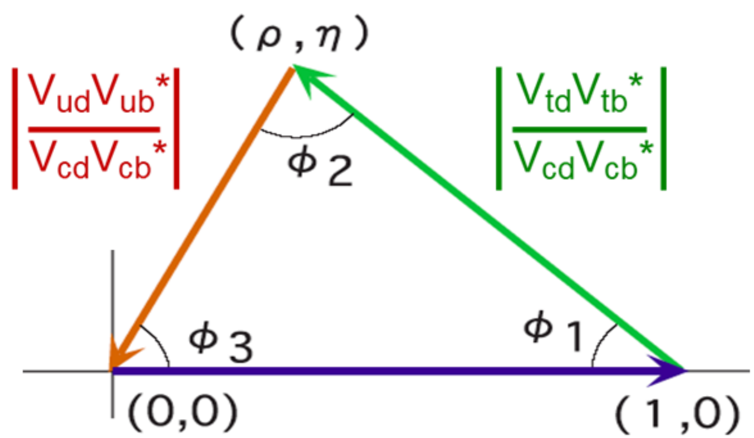
CKM (Cabibbo-Kobayashi-Maskawa) Matrix

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

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.

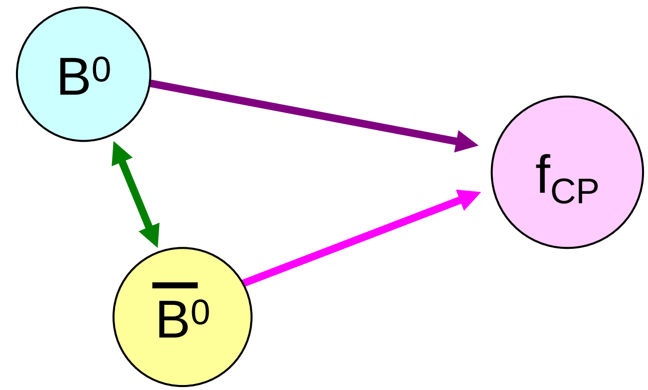


$\phi_1 = \beta$
$\phi_2 = \alpha$
$\phi_3 = \gamma$

CP Violation in B Meson

Mixing-induced CP asymmetry of B mesons

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



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

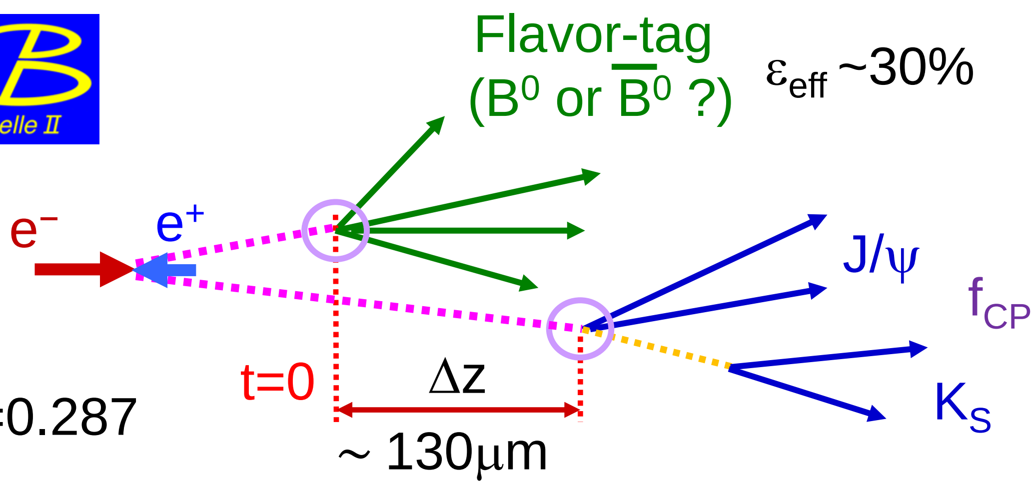
$$= S \sin(\Delta m \Delta t) - C \cos(\Delta m \Delta t)$$

$S = -\xi \sin(2\phi_1)$ for $B \to J/\psi K_S$

$\phi_1 = \beta$

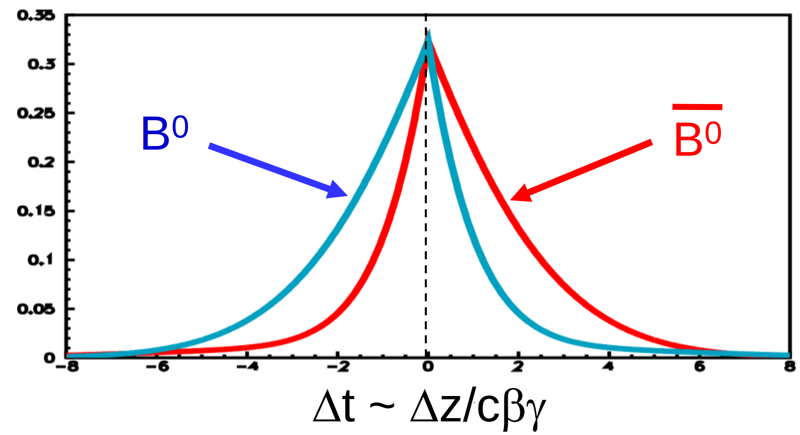
S : mixing induced CPV
C : direct CPV (=−A)

ε_{eff} ~30%



$\beta\gamma$=0.287

measure position instead of time

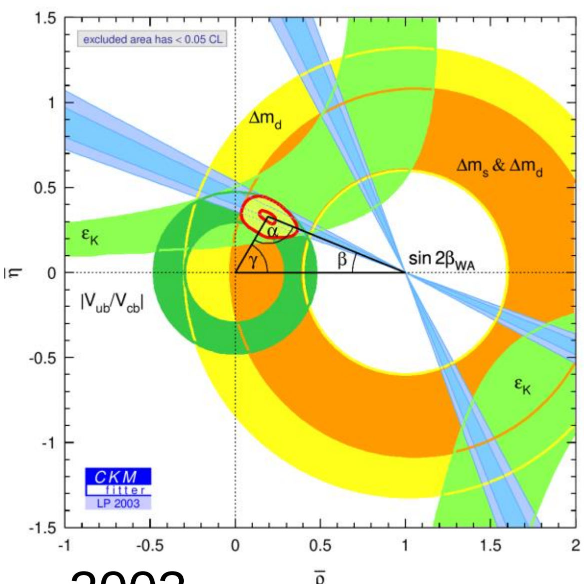


Unitarity Triangle

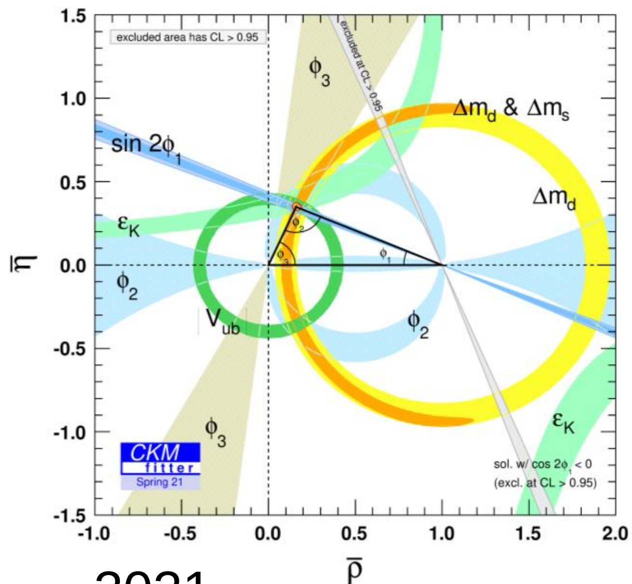
Observation CP violation in B mesons (2001): BaBar and Belle

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

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



2003



2021

?

2008 Nobel Prize

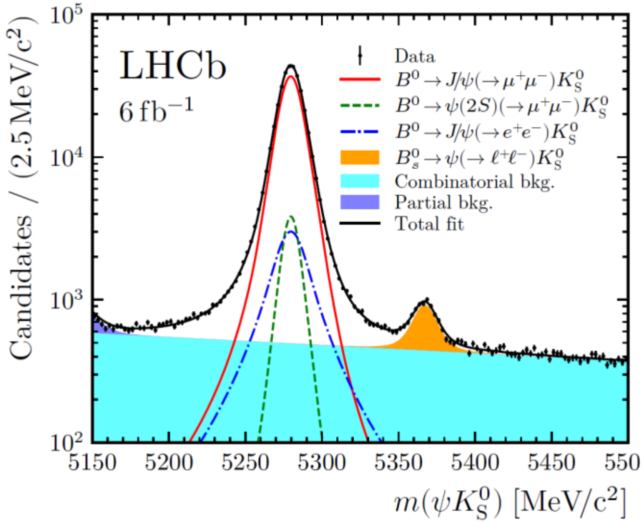
$\phi_1 = \beta$
$\phi_2 = \alpha$
$\phi_3 = \gamma$

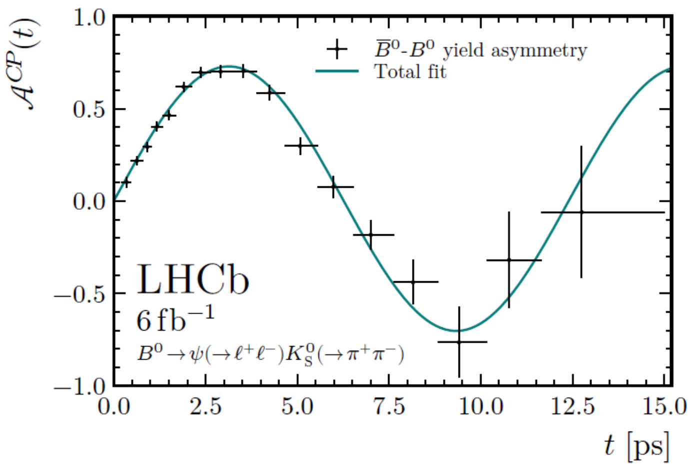
- Precise measurement of the Unitarity Triangle → Test of the SM
  - ✓ “Over-constrain” the triangle.
  - ✓ Still room of New Physics effects.

sin(2β) at LHCb

- New result from LHCb using Run2 data (6 fb^{-1}).
- $B \to J/\psi\ (\to \mu^+\mu^-, e^+e^-)\ K_S$, $\psi(2S)\ (\to \mu^+\mu^-)\ K_S$.

[arXiv:2309.09728]

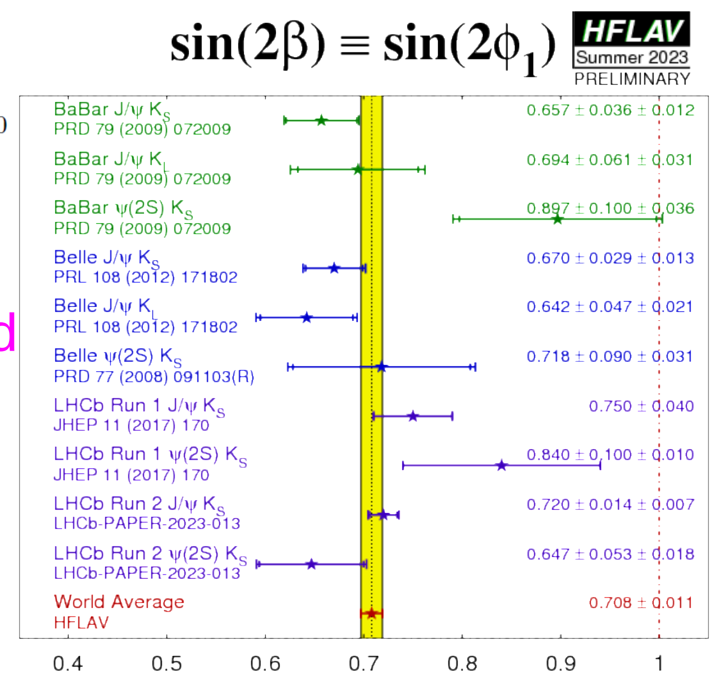




$S(\psi K_S) = 0.717 \pm 0.013 \pm 0.008$

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

statistics dominated



Combined with Run1: $S(\psi K_S) = 0.724 \pm 0.014$

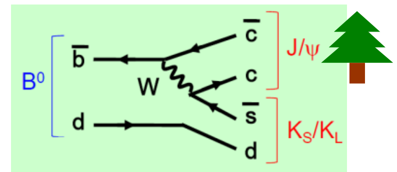
$C(\psi K_S) = 0.004 \pm 0.012$

Most precise result.

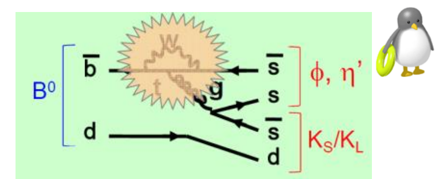
CPV in $B^0 \to \eta' K_S$ at Belle II

- $b \to s$ 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.
- $B \to \eta' K_S$ from Belle II with 362 fb^{-1}

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

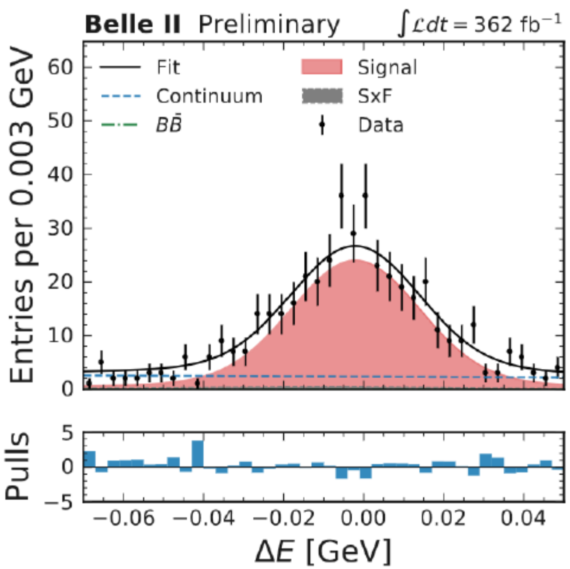


$b \to s$ ($B \to \eta' K^0$)

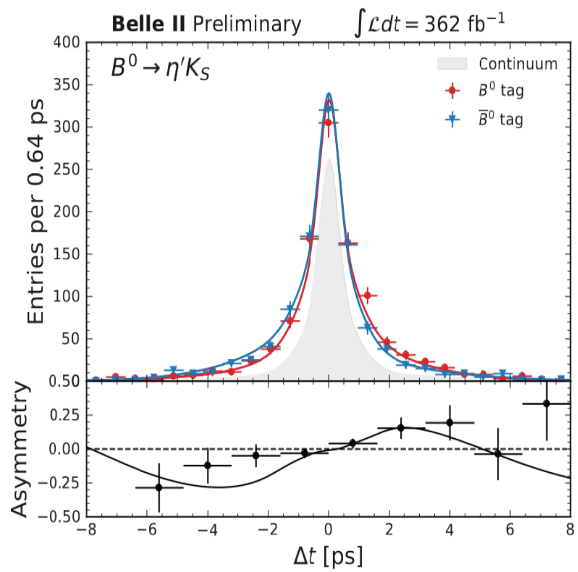


[EPS2023]

387 M $B\bar{B}$



829±35 signal events



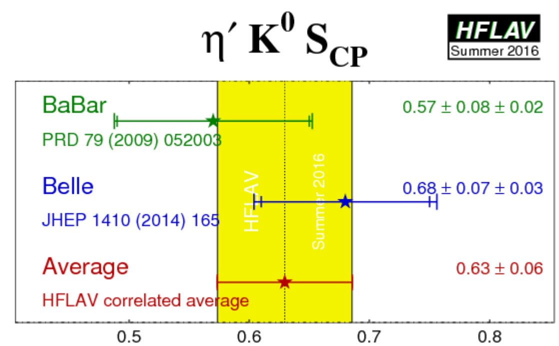
$S = 0.67 \pm 0.10 \pm 0.04$

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

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

467 M

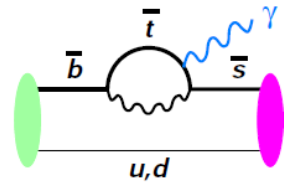
772 M

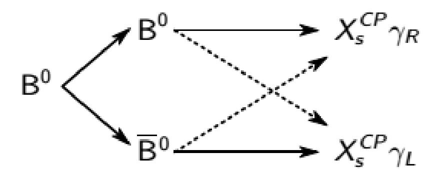


$S(\eta' K_S)$

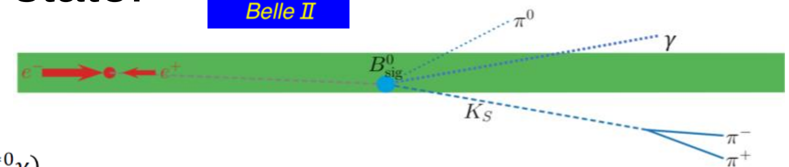
CPV in $B^0 \to K_S\pi^0\gamma$ at Belle II

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





[EPS2023]



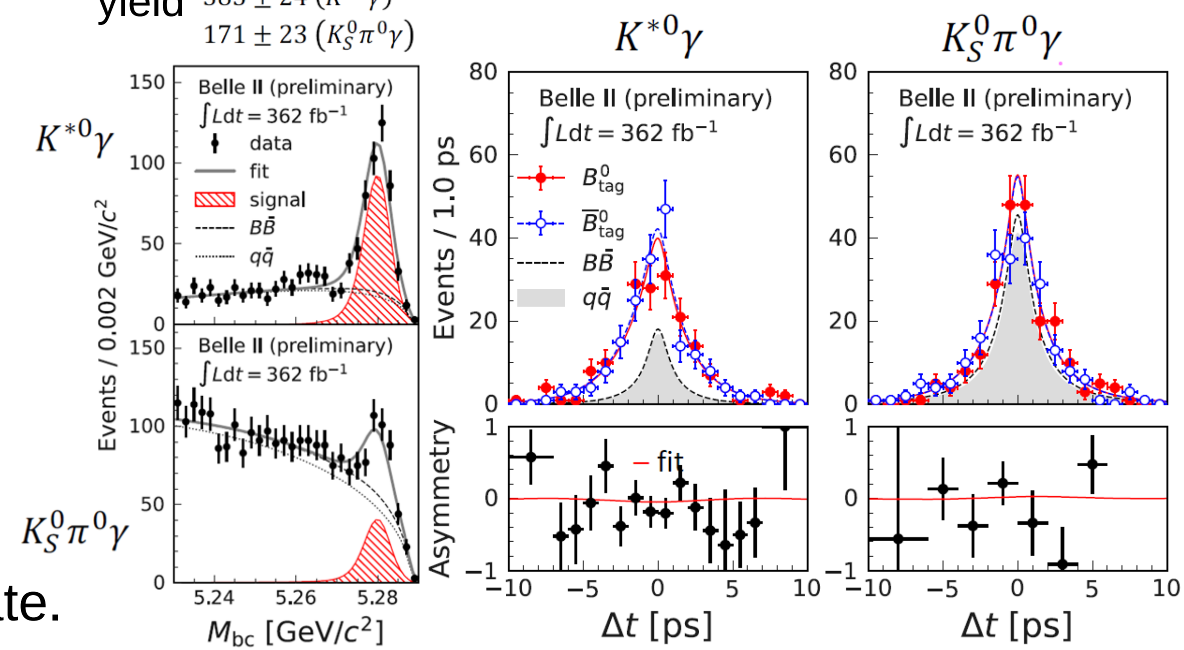
- New Belle II result with 362 fb^{-1}.
- B vertex from K_S only.
- Two $M(K\pi)$ regions: K* [0.8,1.0] GeV and the rest of [0.6,1.8] GeV.

yield $385 \pm 24\ (K^{*0}\gamma)$
$171 \pm 23\ (K_S^0\pi^0\gamma)$

$K^{*0}\gamma$:
$S = 0.00^{+0.27}_{-0.26} \pm 0.03$
$C = 0.10 \pm 0.13 \pm 0.03$
- HFLAV: $S = -0.16 \pm 0.22$ $C = -0.04 \pm 0.14$

$K_S^0\pi^0\gamma$:
$S = 0.04^{+0.45}_{-0.44} \pm 0.10$
$C = -0.06 \pm 0.25 \pm 0.08$
- Belle (2006): $S = 0.50 \pm 0.68$ $C = 0.20 \pm 0.39$

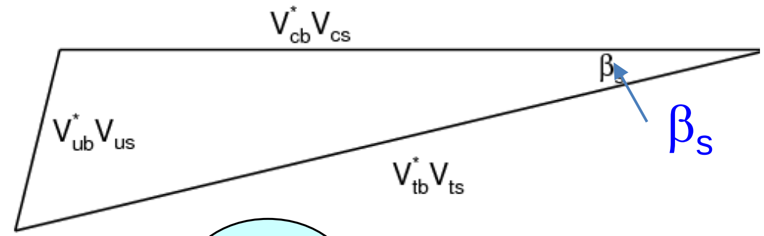
Most precise measurements to date.



$B_s \to J/\psi\ \phi$

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

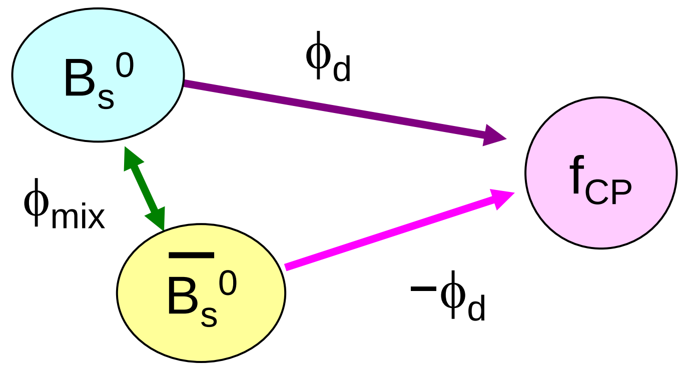
$$V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0$$

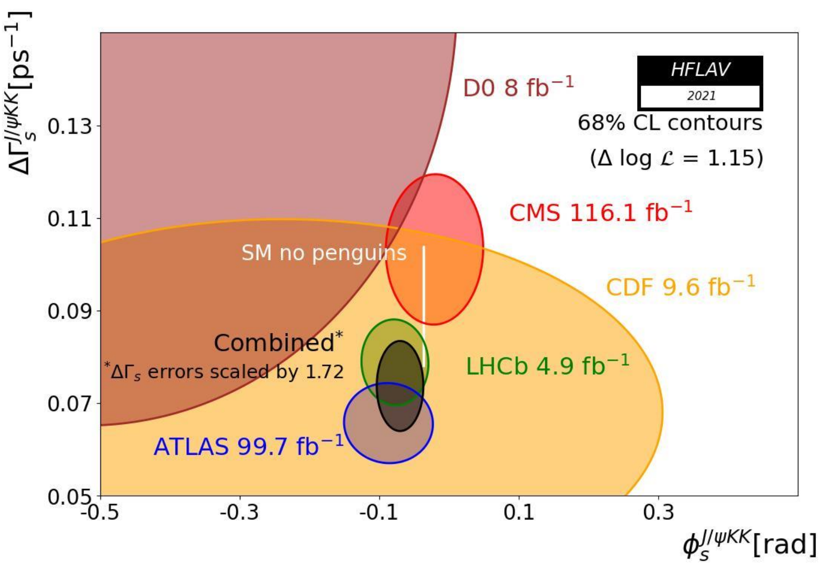


- β_s can be measured in mixing-induced CP violation in B_s decays like $B_s \to J/\psi\ \phi$.

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

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





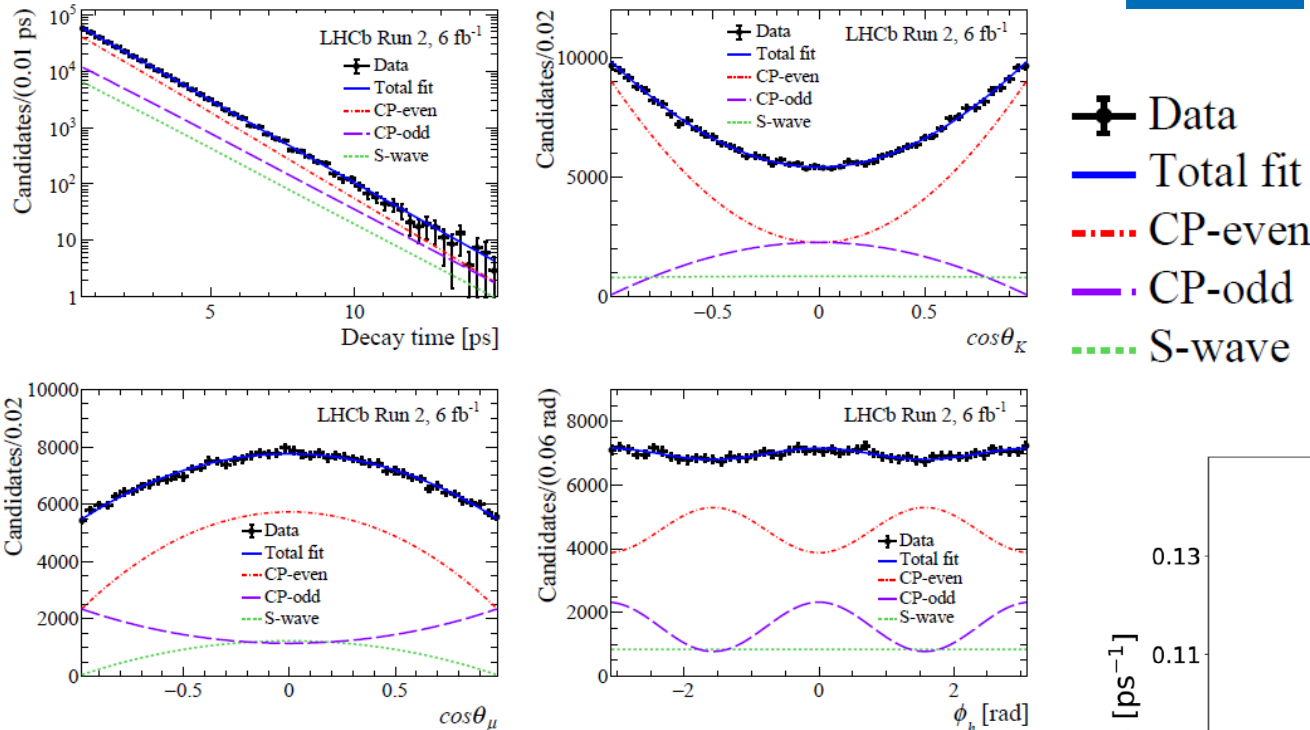
HFLAV 2021

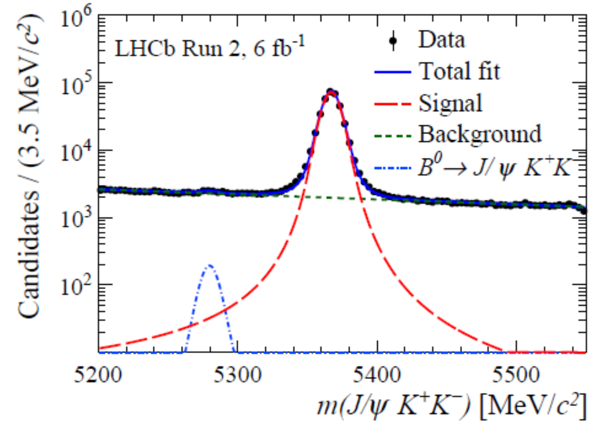
- Excellent time resolution (<100fs) necessary because of fast B_s oscillation
- Flavor tagging
- Two vectors in the final state.
  - ✓ Use angular distributions to extract the CP eigenstate.

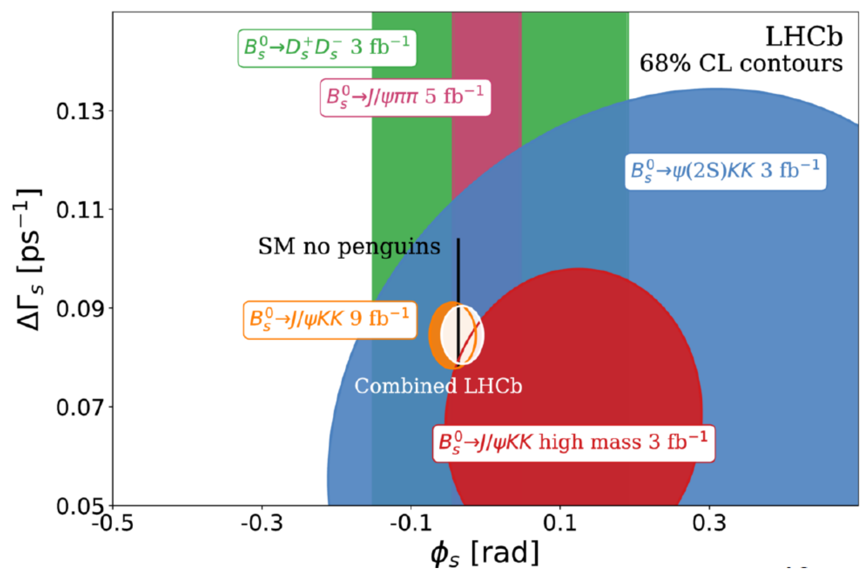
$B_s \to J/\psi\ \phi$ at LHCb

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

[arXiv:2309.09728]







$\phi_s = -0.039 \pm 0.022 \pm 0.006$ rad

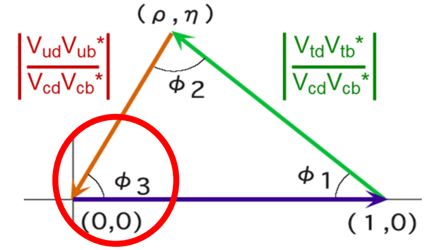
$|\lambda| = 1.001 \pm 0.011 \pm 0.005$

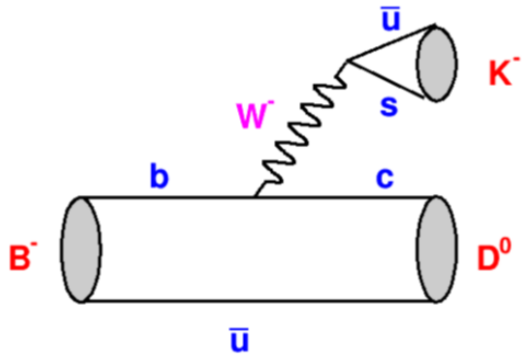
$\Gamma_s - \Gamma_d = -0.0056\,^{+0.0013}_{-0.0015} \pm 0.0014$

$\Delta\Gamma_s = 0.0845 \pm 0.0044 \pm 0.0024$

γ / ϕ_3

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

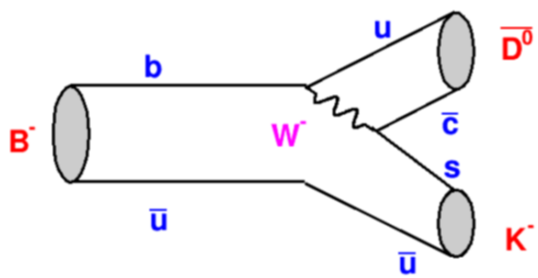




color favored

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

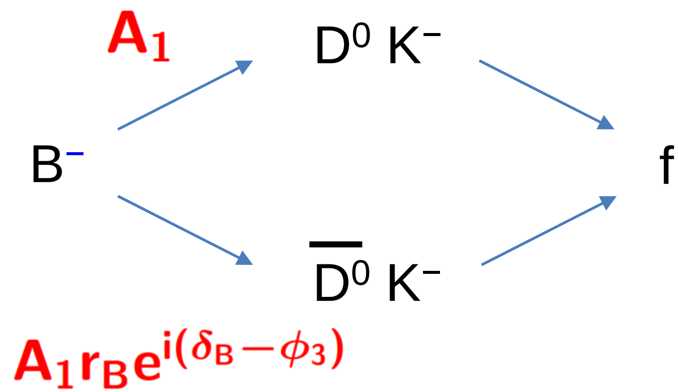
A_1



color suppressed

$B^- \to \bar{D}^0 K^- \approx V_{ub} V_{cs}^*$

$A_1 r_B e^{i(\delta_B - \phi_3)}$



- 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.

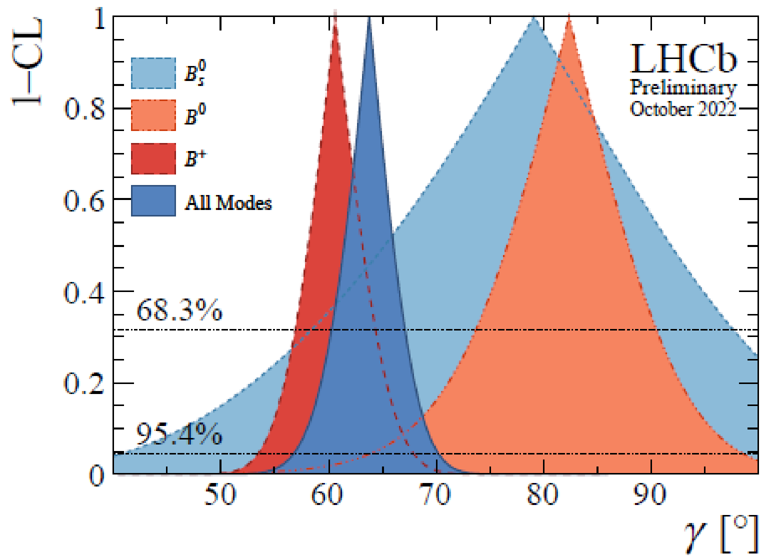
γ / ϕ_3

- GLW (Gronau-London-Wyler) [PLB 253 (1991) 483, PLB 265 (1991) 172]
  - ✓ $B^{\pm} \rightarrow D^0_{CP} K^{\pm}$
  - ✓ 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 (=ϕ_3)

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



[LHCb-CONF-2022-003]

$\gamma = (63.8^{+3.5}_{-3.7})°$

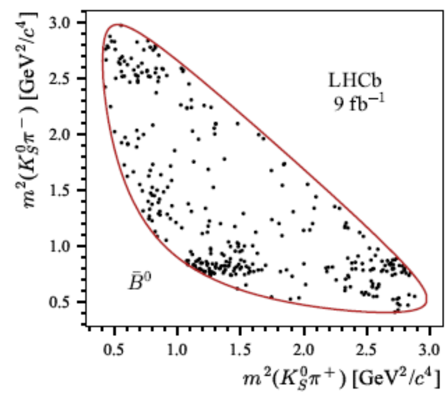
Global fit by CKM fitter

$\gamma = (65.5^{+1.1}_{-2.7})°$

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

- A few more new results came this year (not included above)
  - ✓ e.g., $B^0 \to D K^*$ with $D \to K_S h^+h^-$ [arXiv:2309.05514].

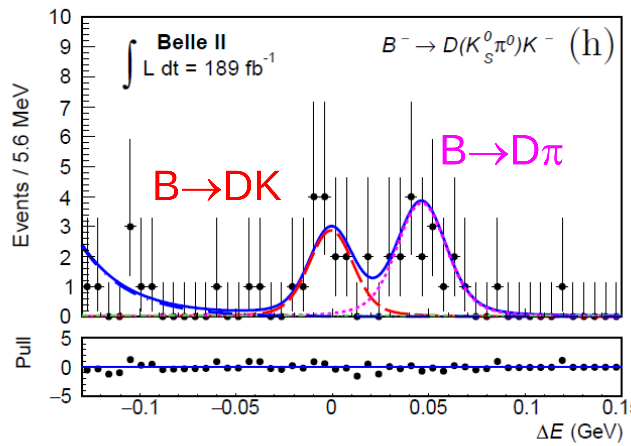
$\gamma = (49^{+22}_{-19})°$



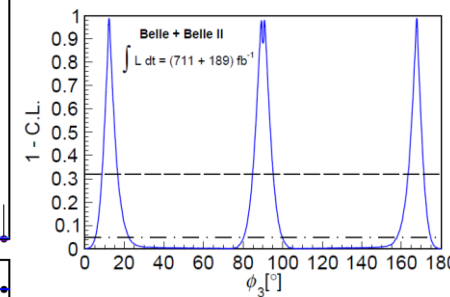
Belle + Belle II Combined ϕ_3 (=γ)

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

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

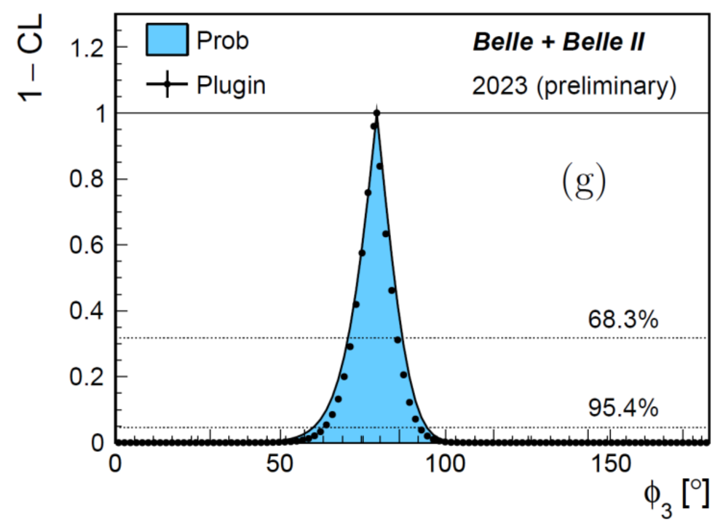


[arXiv:2308.05048]



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

[CKM2023]



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

$\phi_3 = (78.6 \pm 7.3)^\circ$ Consistent with WA.

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

Other Measurements

Many topics cannot be covered in this talk

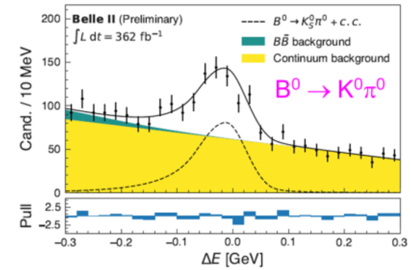
- B_d and B_s mixing
  - ✓ Measurements by LHCb
- $|V_{ub}|$ and $|V_{cb}|$ from semi-leptonic B decays
  - ✓ Recent progress in Belle, Belle II
- Measurement of ϕ_2 / α
- ϕ_s from loop diagram
- ….

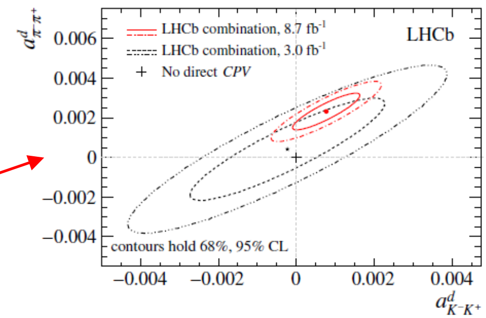
and

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

[arXiv:2310.06381 (accepted at PRD)]

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

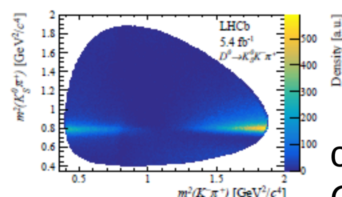




[PRL 131, 091802]

[arXiv:2310.19397]

$D^0 \to K^0_S K^\pm \pi^\mp$



[JHEP09(2023)129]

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

consistent with CP symmetry

Prospects

LHCb

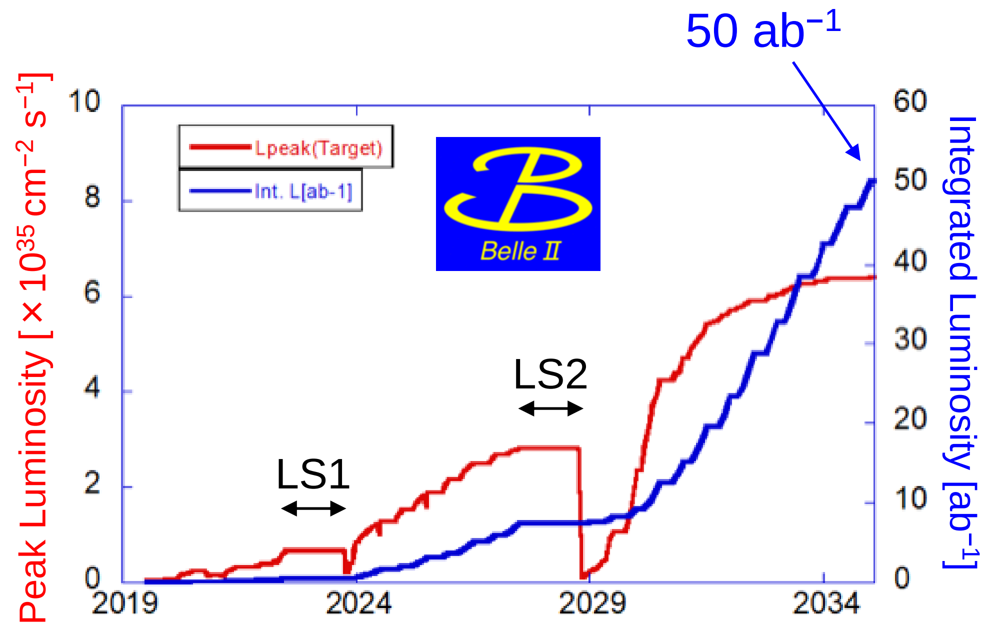
9 fb^{-1} — Goal: 50 fb^{-1} — Goal: 300 fb^{-1}

Upgrade I — Upgrade Ib — Upgrade II

Run 1	LS1	Run 2	LS2		Run 3	LS3	Run 4	LS4	Run 5	LS5	Run 6
2011 2012	2013 2014	2015 2016 2017 2018	2019 2020 2021	2022	2023 2024 2025	2026 2027 2028	2029 2030 2031 2032	2033 2034	2035 2036 2037 2038	2039	2040 2041

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

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

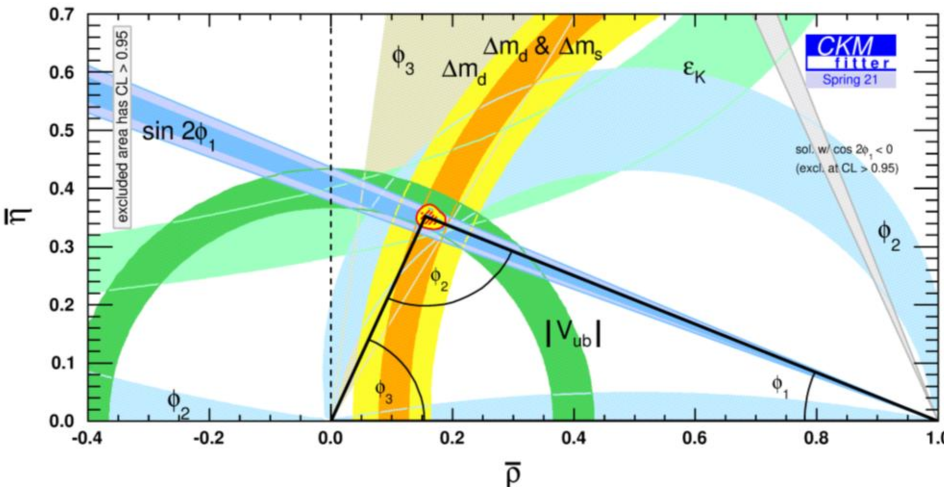


[LHCb-PUB-2022-012, arXiv:2203.11349]

Summary and Conclusion

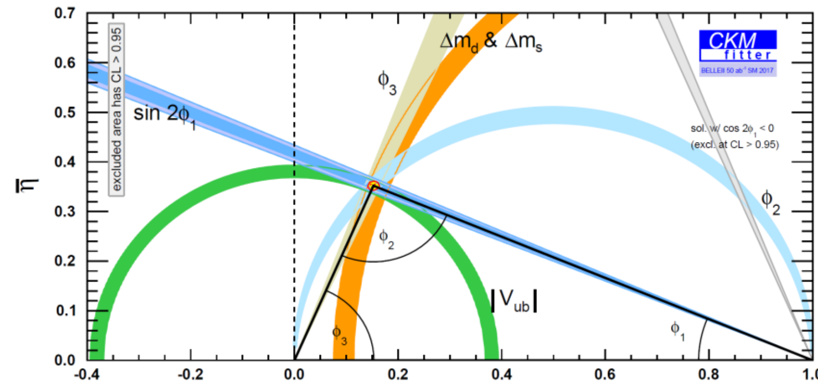
- Precise measurements of Unitarity Triangle provides an interesting test for New Physics.
- LHCb has been improving the measurements.
- Belle II started and has joined the game.
  - ✓ Unique measurements for some modes.
- Consistent with the SM or not ?

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



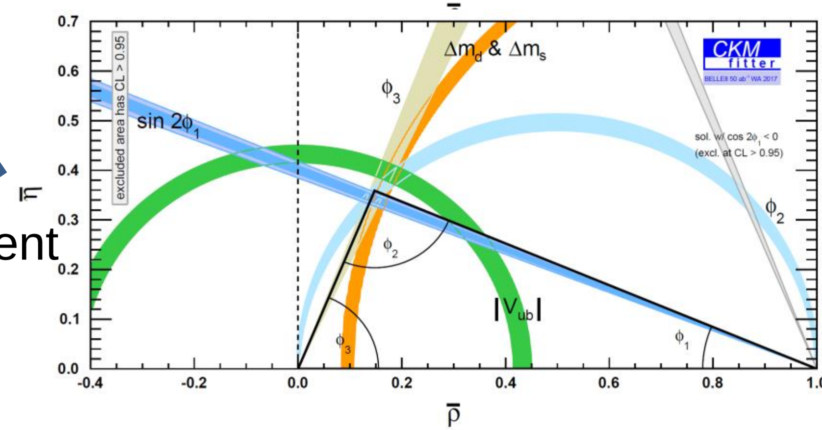
consistent

?



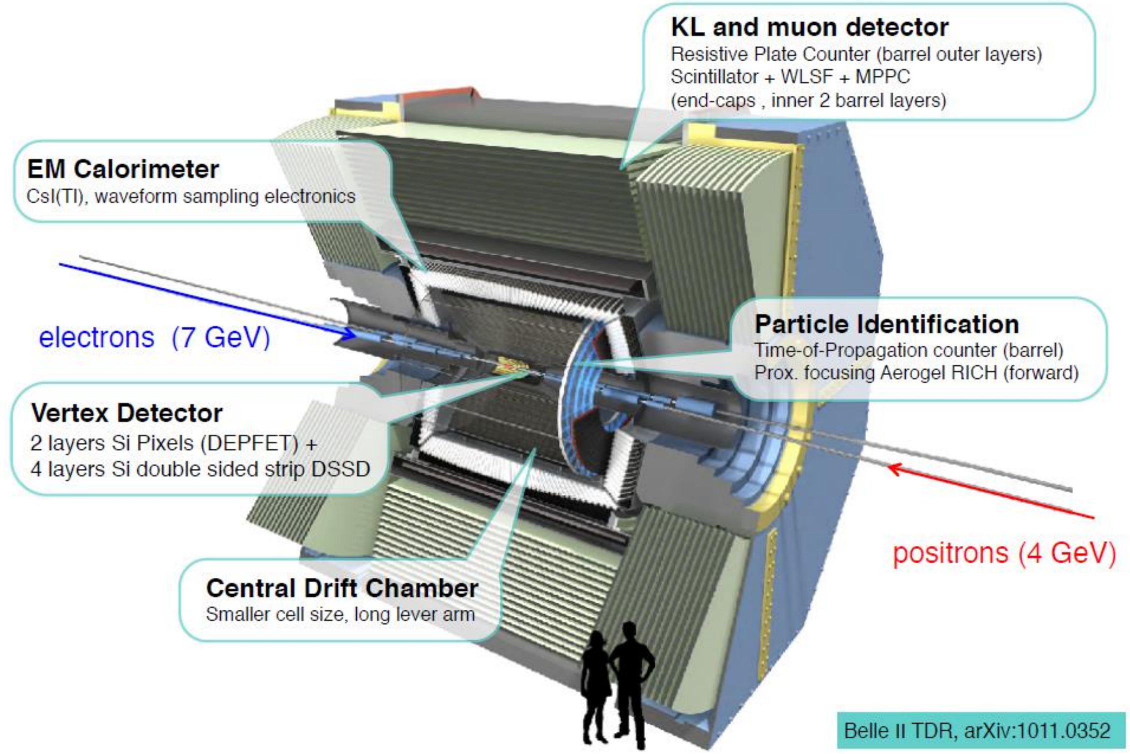
?

inconsistent



Backup

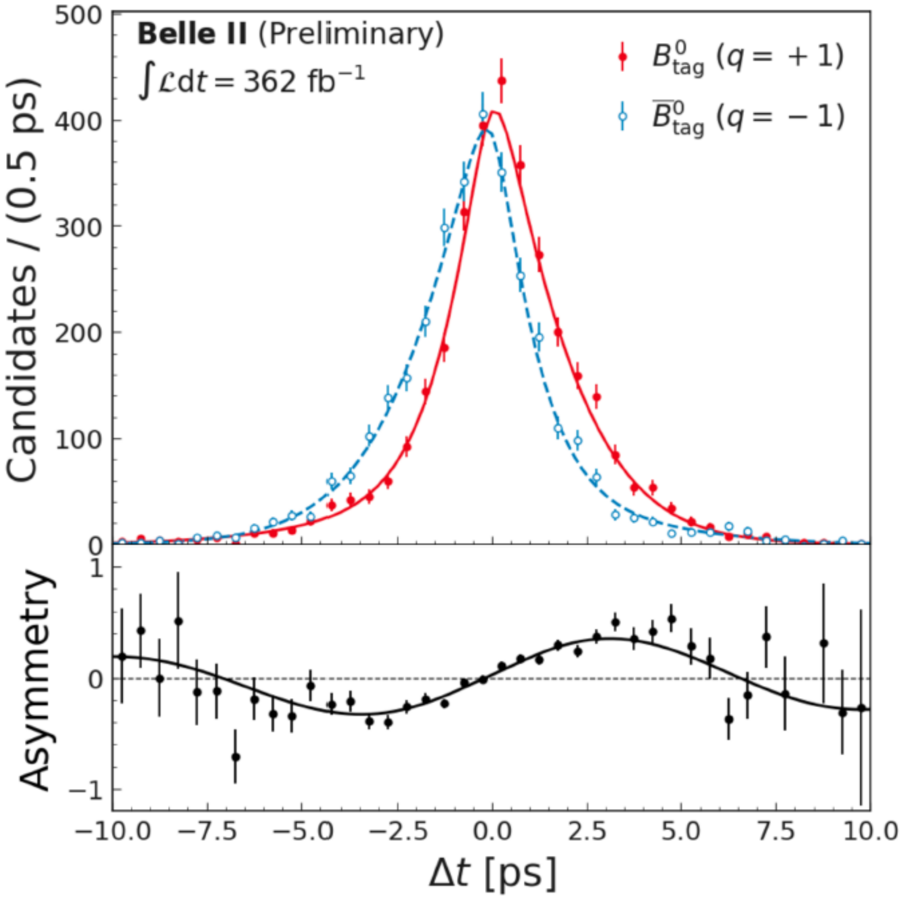
SuperKEKB and Belle II



$e^+e^- \to \Upsilon(4S) \to B\bar{B}$

- 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 $B^0 \to J/\psi K_S$ at Belle II



- τ_{B^0} and Δm_d (PRD107(2023)9,L091102)
  - Measured in $B^0 \to D^{(*)-}\pi^+$
  - $\tau_{B^0} = 1.499 \pm 0.013 \pm 0.008$ 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 ~8%

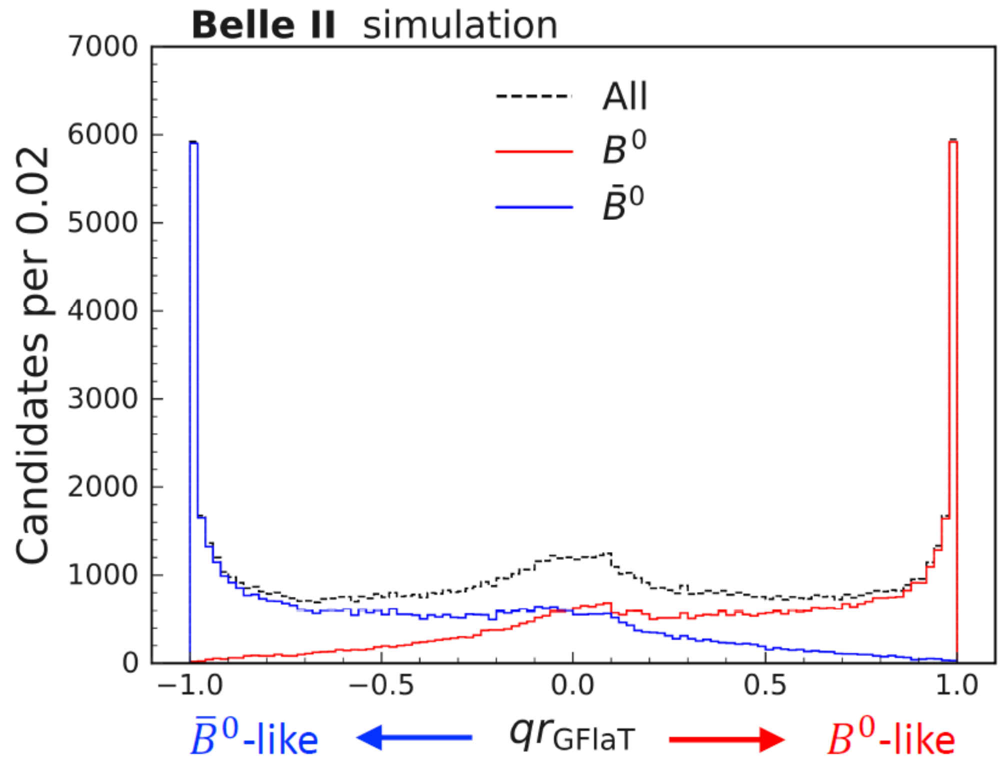
GFlaT: GNN Flavor Tagger

- **Motivation**
  - Category-based BDT does not consider relations b/w particles
    - e.g., $B^0 \to K^- X$ fakes $\bar{B}^0 \to D^0/D^+ \to K^-$ chain
- **Graph Neural Network**
  - Node = particle, Edge = relation

    → <u>Utilize characteristics of relations</u>
    - e.g., prompt/secondary K^- can be distinguished
  - Effective tagging efficiency in data:

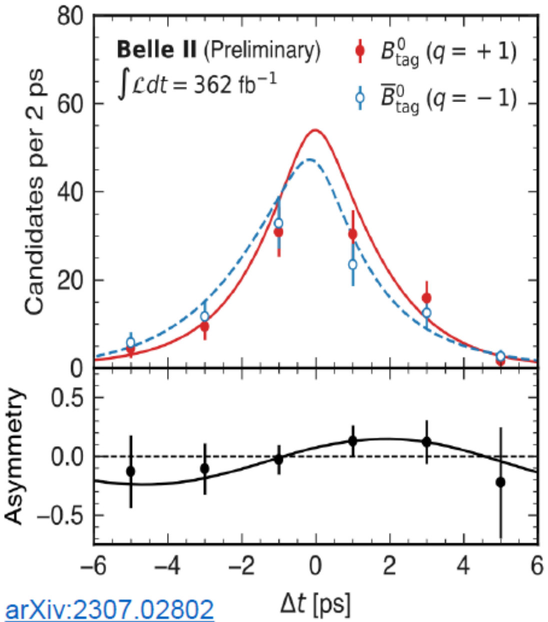
    $(31.68 \pm 0.45 \pm 0.41)\%$

    $\rightarrow (37.40 \pm 0.43 \pm 0.34)\%$ <u>18% gain</u>
    - c.f. $28.8 \pm 0.6\%$ in Belle



CPV in b→s at Belle II

$B^0 \to \varphi K_S$

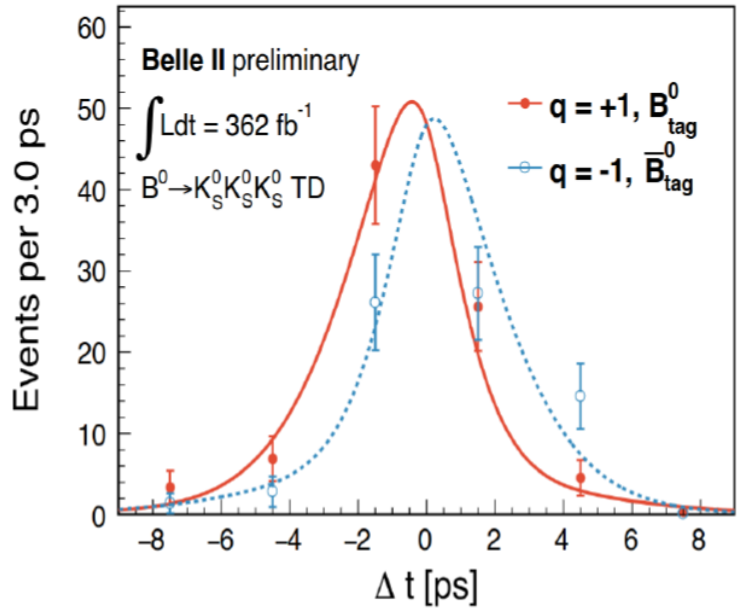


arXiv:2307.02802

$$C_{CP} = -0.31 \pm 0.20 \pm 0.05$$
$$S_{CP} = 0.54 \pm 0.26^{+0.06}_{-0.08}$$

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

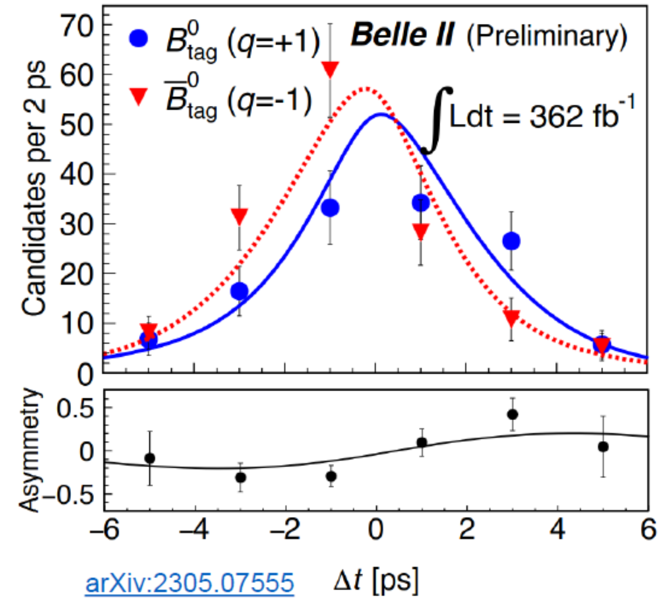
$B^0 \to K_S K_S K_S$



$$C_{CP} = -0.07 \pm 0.20 \pm 0.05$$
$$S_{CP} = -1.37^{+0.35}_{-0.45} \pm 0.03$$

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

$B^0 \to K_S \pi^0$



arXiv:2305.07555

$$C_{CP} = -0.04 \pm 0.15 \pm 0.05$$
$$S_{CP} = 0.75^{+0.20}_{-0.23} \pm 0.04$$

HFLAV: $C_{CP} = 0.01 \pm 0.10$ $S_{CP} = 0.57 \pm 0.17$

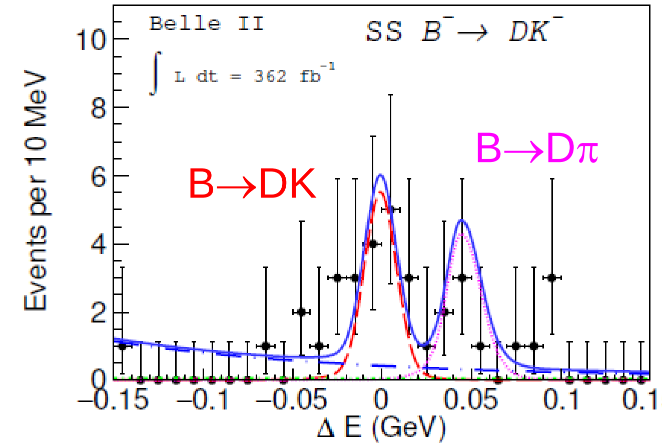
Belle + Belle II Combined ϕ_3 (=γ)

- $B^\pm \to DK^\pm$, $D\pi^\pm$ with $D \to K_S K^\pm \pi^\mp$ (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
$D \to K^+\pi^-$	$R_D^{K\pi}$	$(3.44 \pm 0.02) \times 10^{-3}$	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		
$D \to K^+\pi^-\pi^0$	$r_D^{K\pi\pi^0}$	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		
	$\delta_D^{K\pi\pi^0}$	$(196 \pm 15)^\circ$		
$D \to K_S^0 K^-\pi^+$	$(r_D^{K_S^0 K\pi})^2$	0.356 ± 0.034	CLEO	[30]
	$\kappa_D^{K_S^0 K\pi}$	0.94 ± 0.12		
	$\delta_D^{K_S^0 K\pi}$	$(-16.6 \pm 18.4)^\circ$		
	$(r_D^{K_S^0 K\pi})^2$	0.370 ± 0.003	LHCb	[31]
$B^+ \to Dh^+$	$R_{\rm GLS}$	0.0789 ± 0.0027	PDG	[32]

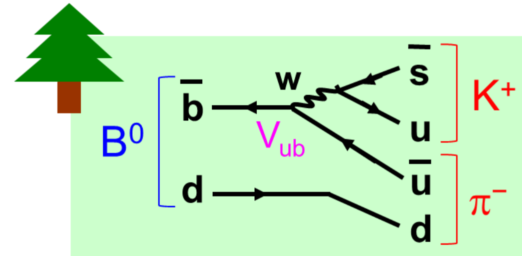


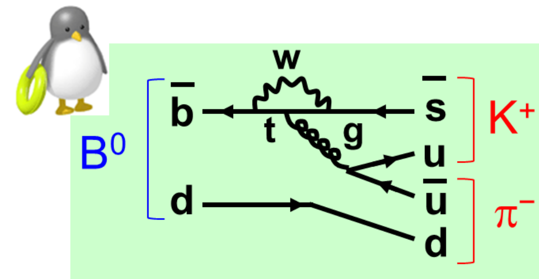
$$A_{\rm SS}^{DK} = 0.055 \pm 0.119 \pm 0.020,$$
$$A_{\rm OS}^{DK} = 0.231 \pm 0.184 \pm 0.014,$$
$$A_{\rm SS}^{D\pi} = 0.046 \pm 0.029 \pm 0.016,$$
$$A_{\rm OS}^{D\pi} = 0.009 \pm 0.046 \pm 0.009,$$
$$R_{\rm SS}^{DK/D\pi} = 0.093 \pm 0.012 \pm 0.005,$$
$$R_{\rm OS}^{DK/D\pi} = 0.103 \pm 0.020 \pm 0.006,$$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

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}.





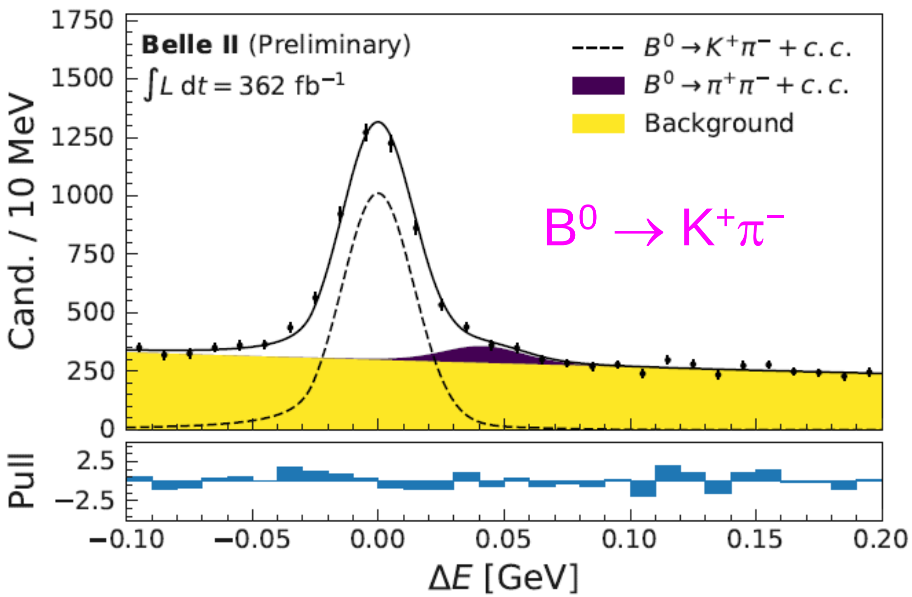
[M.Gronau, PLB627 (2005) 82]

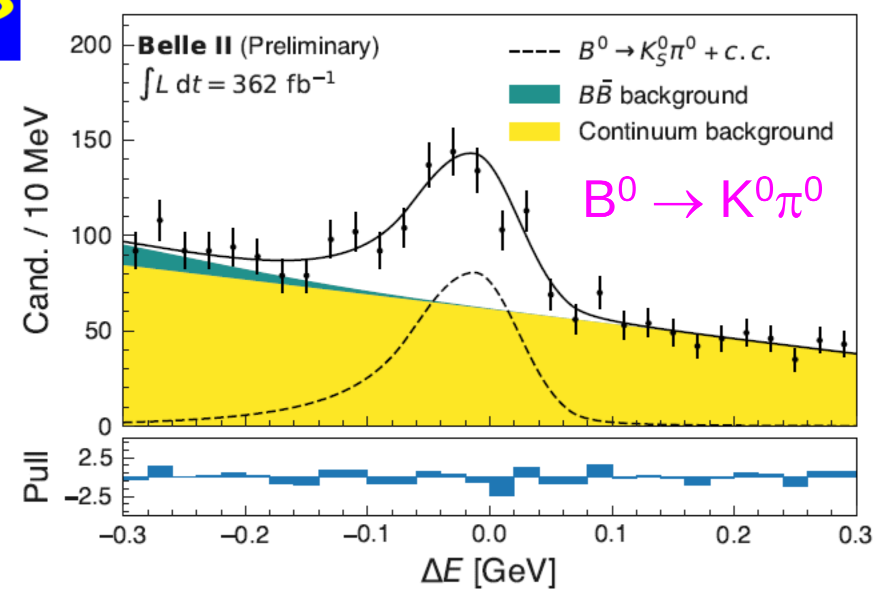
$$I_{K\pi} = \mathcal{A}_{CP}^{K^+\pi^-} + \mathcal{A}_{CP}^{K^0\pi^+}\frac{\mathcal{B}_{K^0\pi^+}}{\mathcal{B}_{K^+\pi^-}}\frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{CP}^{K^+\pi^0}\frac{\mathcal{B}_{K^+\pi^0}}{\mathcal{B}_{K^+\pi^-}}\frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{CP}^{K^0\pi^0}\frac{\mathcal{B}_{K^0\pi^0}}{\mathcal{B}_{K^+\pi^-}}$$

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

$B \to K\pi$ (sum-rule) from Belle II

[arXiv:2310.06381 (accepted at PRD)]





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

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

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

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

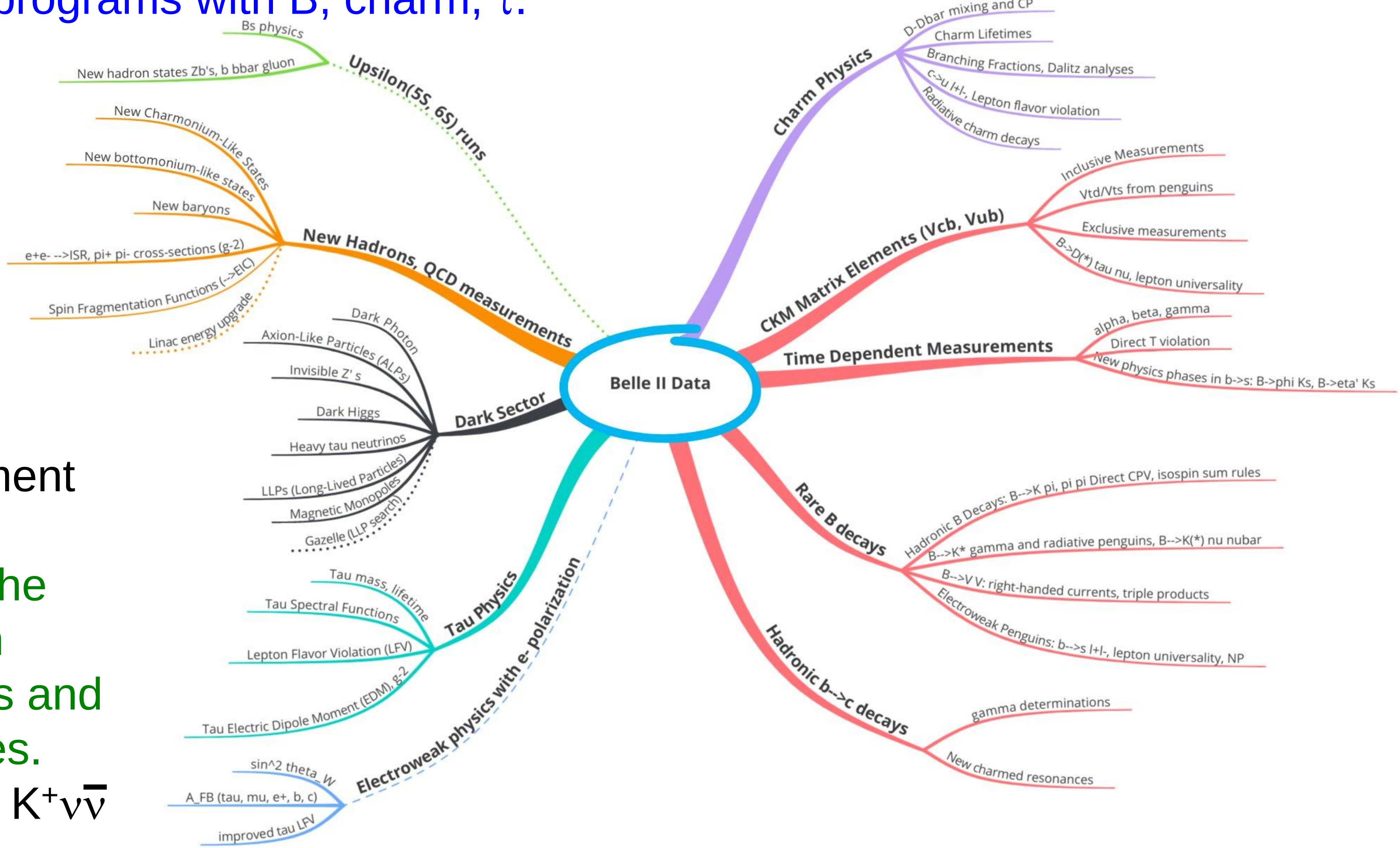
from the time-integrated analysis. This is combined with the time-dependent analysis.

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

- 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.



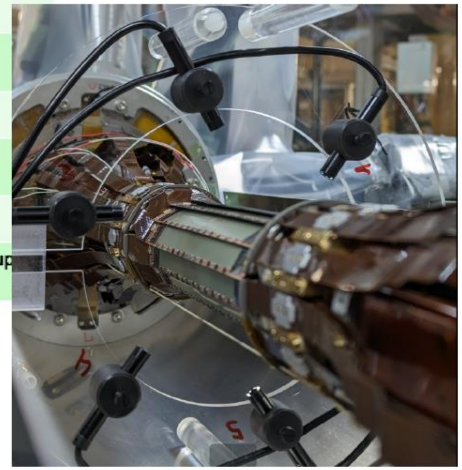
- Clean environment (e^+e^- collider) : advantage for the final states with neutral particles and missing particles.
  - ✓ e.g. $B^+ \to K^+ \nu\bar{\nu}$

LS1 @ SuperKEKB, Belle II

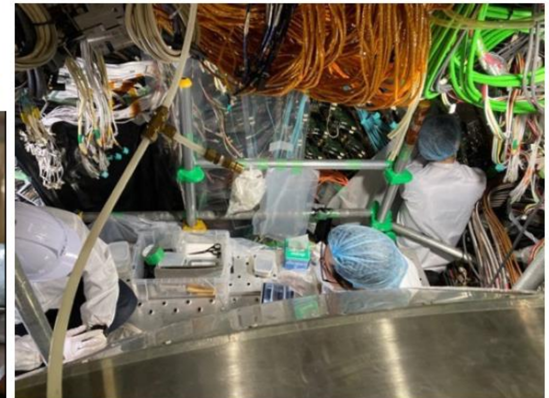
PXD/SVD	PXD commissioning plan in KEK, and VXD reinstallation. SVD 3/6-mixed mode.
CDC	Improvement in gas circulation and monitoring
TOP	TOP MCP-PMT replacement
ECL	Improvement in pedestal correction Gain adjustment on ShaperDSP
KLM	BB2 efficiency recovery Reinforcement of monitoring system
TRG	Optimization 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



VXD extraction in May

CDC FE reinstallation work

SVD standalone commissioning

but also DAQ upgrade, KLM work, ...

LS1 @ SuperKEKB, Belle II

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.