

Flavor Physics

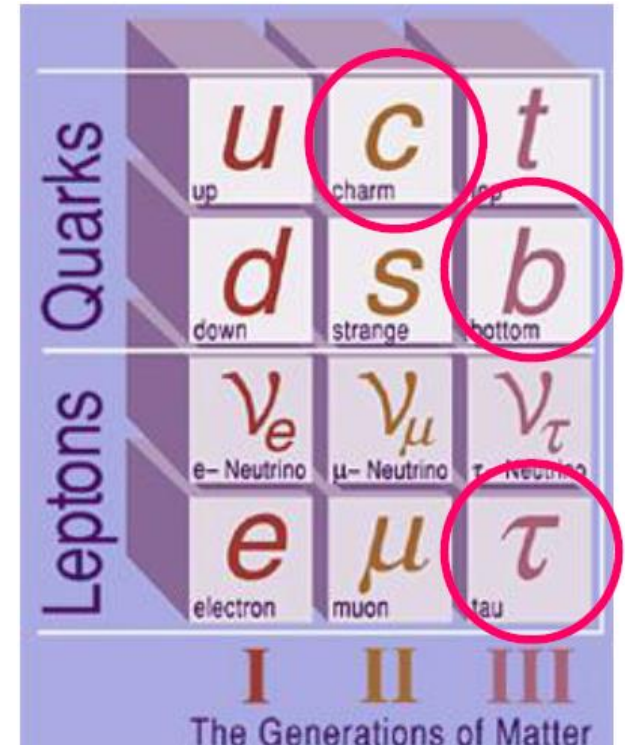
Alex Bondar

Outline

- Introduction
 - a) Flavor Physics and Experiments
 - b) SuperKEKB and Belle II
- $B \rightarrow K\nu\bar{\nu}$, $R(D)$, $R(D^*)$
- CP Violation
- Prospects

Flavor

- Flavor = species of the quarks and leptons
- Only weak interaction changes the species of the quarks and leptons.
- Heavy flavor: c , b , τ
 - ✓ Hadrons with c , b : D , D_s , B , B_s , Λ_b ...
 - ✓ Many kinds of decay modes.
- Precise measurements of the decays can provide information of the physics beyond the Standard Model (SM).
 - ✓ Loop diagrams: New Physics (NP) particles can virtually contribute to the decays
 - ✓ Observables (branching fraction etc.) to be compared with the SM expectation.
- Signature sensitive to Beyond SM (BSM).
 - ✓ Lepton Flavor Violation (LFV): inhibited at the SM
 - ✓ Lepton Flavor Universality (LFU): SM interaction does not depend on the lepton species (e , μ , τ).
 - ✓ CP asymmetry, ... : observables with precise SM prediction
 - ✓ Smaller SM contribution: Rare Decays

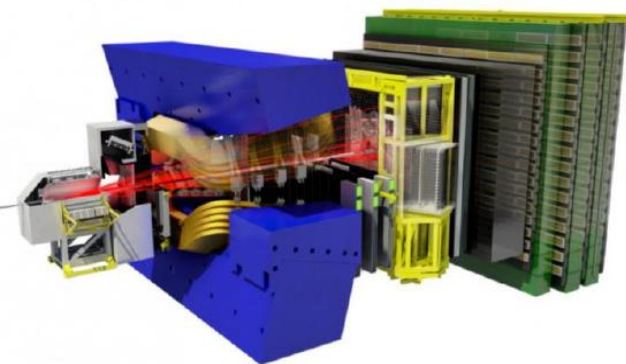


Heavy Flavor Physics Experiments

Hadron collider

LHC @ CERN
LHCb, ATLAS, CMS

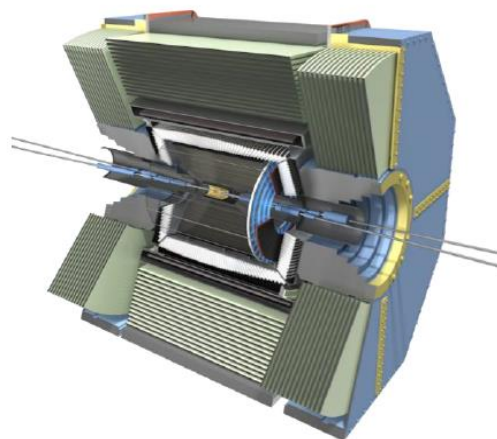
- pp collision



LHCb : forward detector
optimized for b and c studies.

$e^+ e^-$ collider

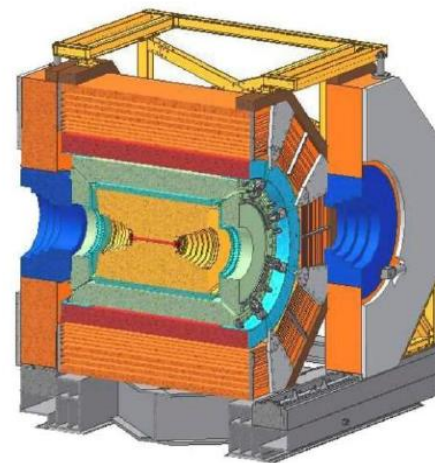
SuperKEKB @ KEK
Belle II



~10.58 GeV

BaBar (1999-2006),
Belle (1999-2010)

BEPCII @ IHEP(China)
BESIII

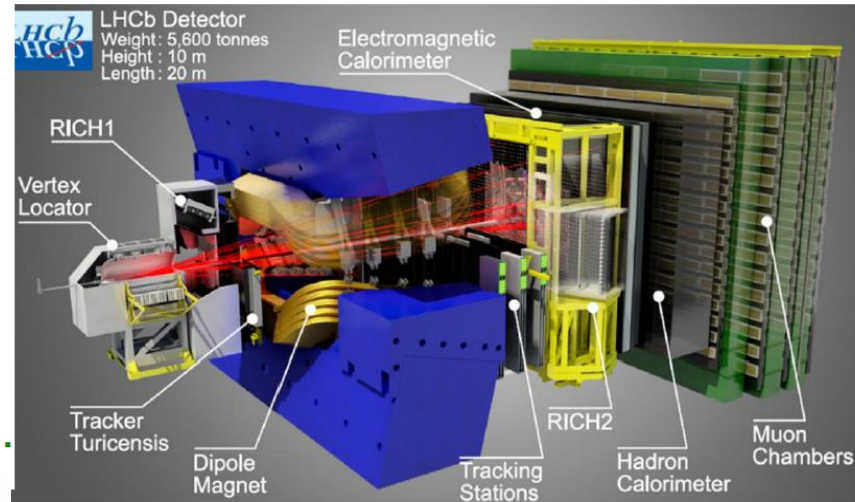


2-5 GeV

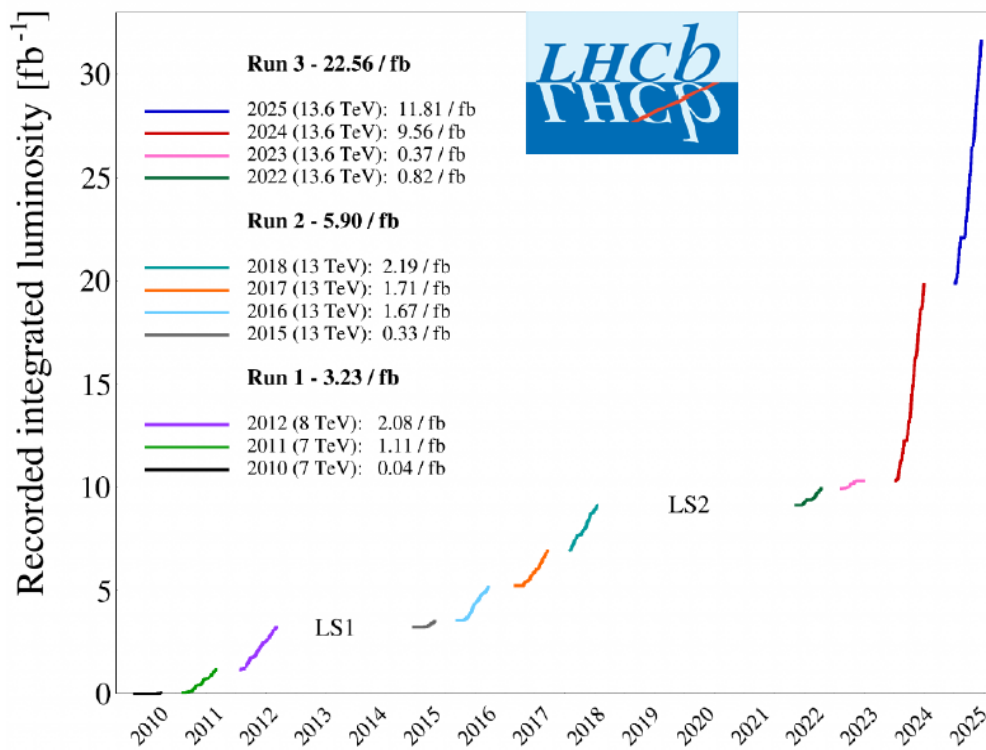
- charm, exotic hadrons...

LHCb

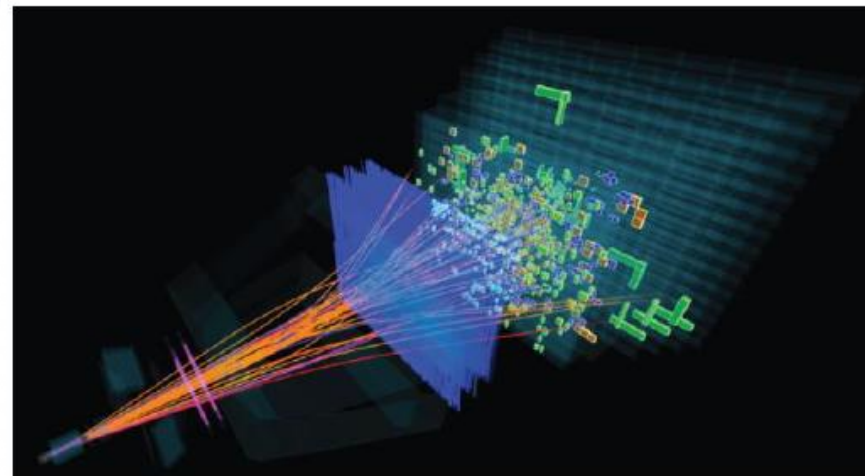
- Excellent vertex resolution to separate b, c (weak) decays.
- Particle identification (PID).
- Huge cross section of b.
- Production of B_s , Λ_b
- Many particles at collision.
- Neutral particles reconstruction not trivial.



Total recorded luminosity – pp – 31.7 fb^{-1}



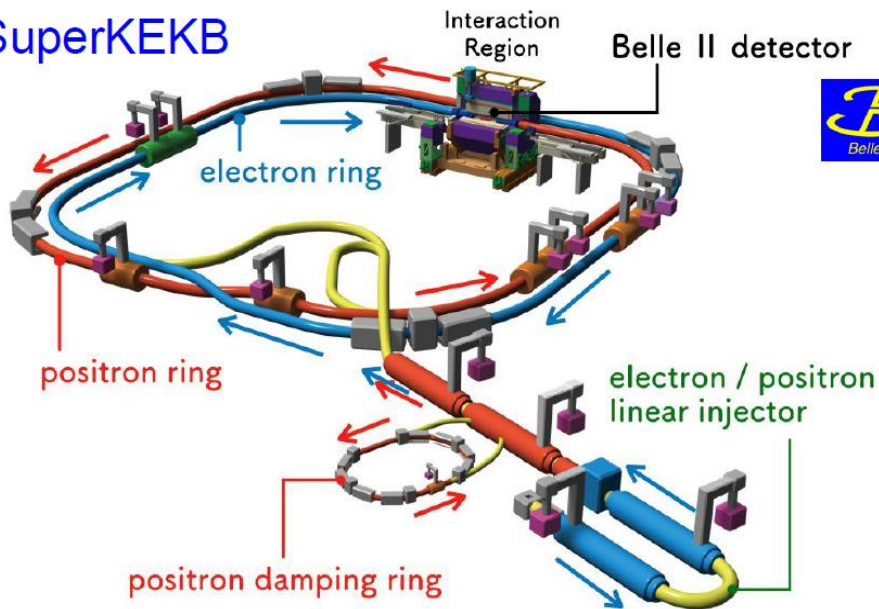
$$\sigma(pp \rightarrow H_b X) \cong 50 \div 100 \mu\text{b}$$



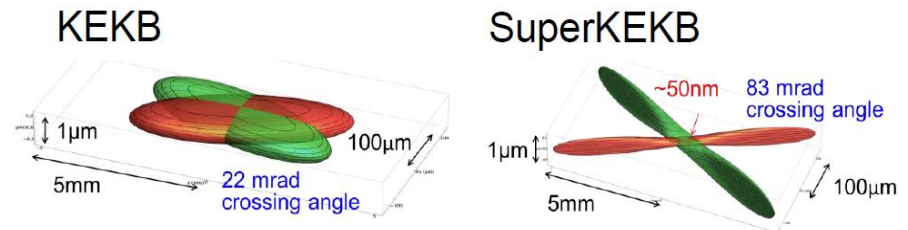
SuperKEKB

- Located at KEK, Tsukuba, Japan
- **SuperKEKB**: asymmetric e^+e^- collider (4 GeV e^+ + 7 GeV e^-)
 - ✓ Nano-beam scheme to achieve high luminosity
- **Belle II**: flavor physics experiment at SuperKEKB
- Successor of KEKB, Belle in operated in 1999-2010
 - ✓ Verified Kobayashi-Maskawa theory in the study of CP violation in B mesons

SuperKEKB

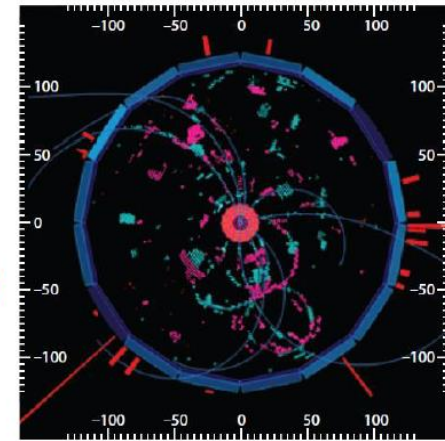
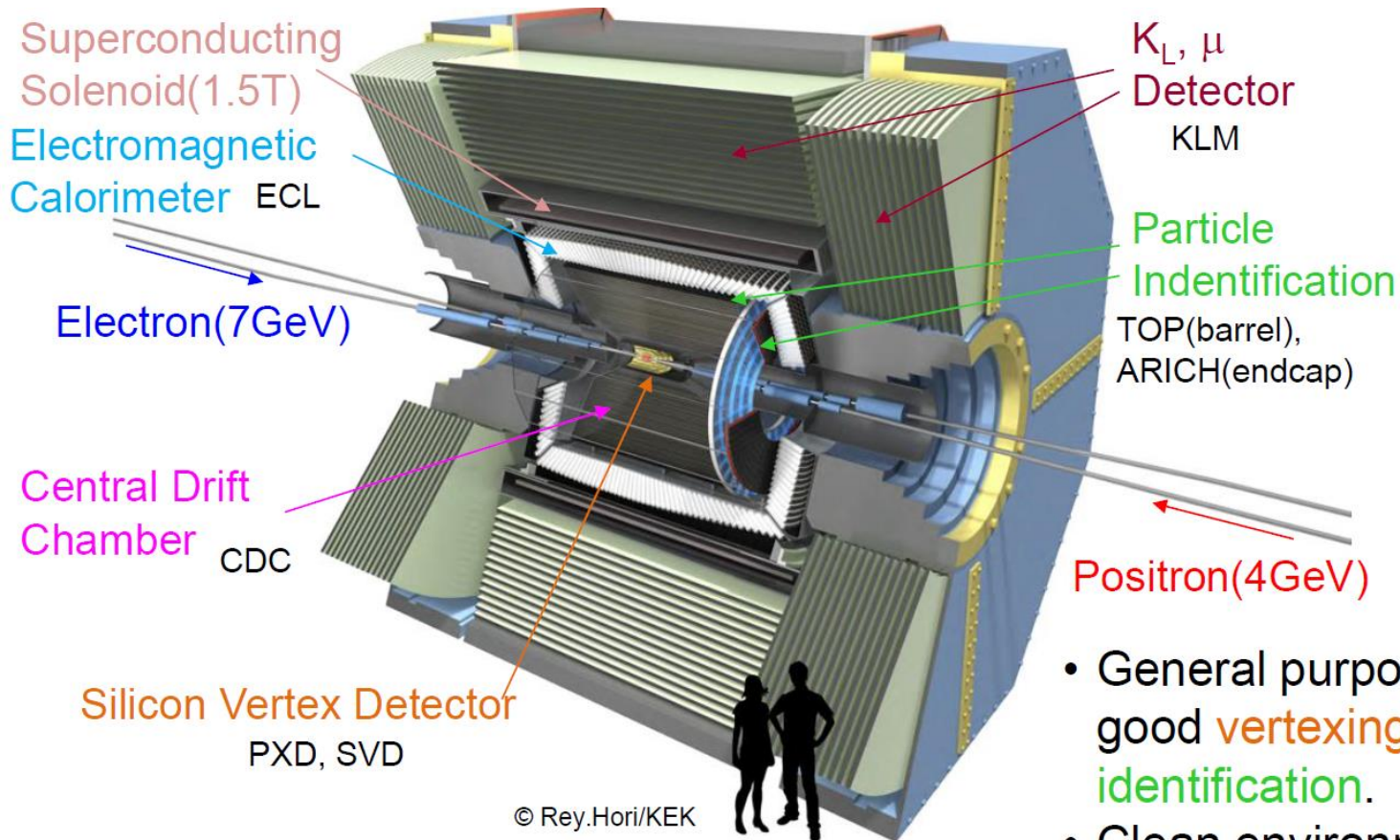


nano beam scheme: new technology



- Luminosity $5.1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ achieved (Dec. 2024):
 - ✓ World record ($\sim \times 2.5$ of KEKB)
 - ✓ Aiming one order higher.
- 590 fb^{-1} of data accumulated so far.

Belle II



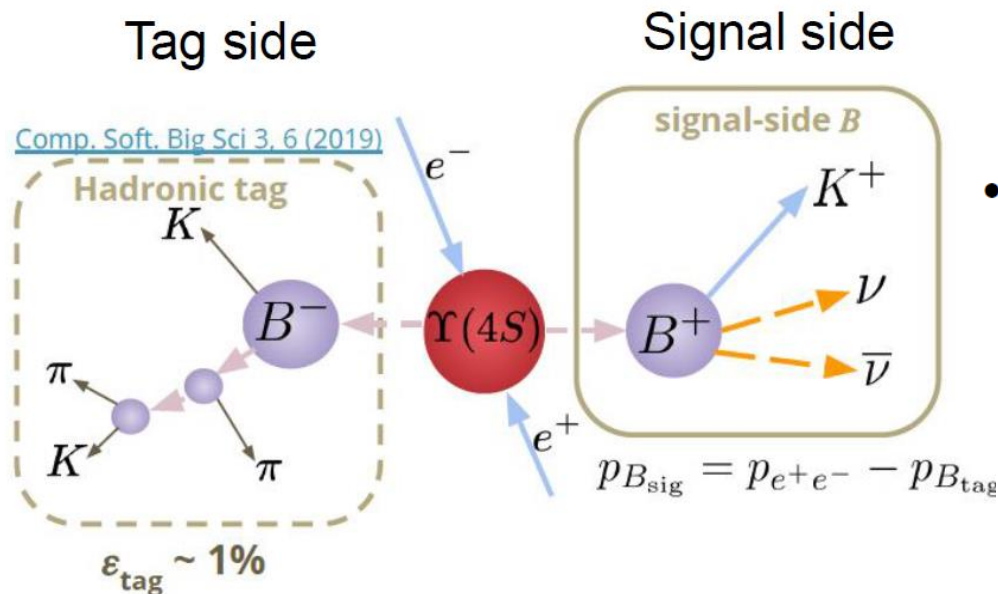
Belle II Detector (8m×8m×8m, 1400t)

- General purpose 4π detector with good **vertexing** and **particle identification**.
- Clean environment: **advantage for the final states with neutral particles and missing particles**

B mesons studies at $\Upsilon(4S)$

- B mesons are produced in pair in Belle II.
- Clean environment: advantage for the final states with neutral particles and missing particles.

$$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B} \quad (1.1\text{nb})$$



Analysis technique:

“Tag” one B \rightarrow the rest of particles come from the other (signal) B.

- Useful to study B decays with neutrinos.
 - ✓ $B \rightarrow K\nu\nu$, $B \rightarrow D^*\tau\nu$
- A few methods for tagging
 - ✓ hadronic tag
 - ✓ semi-leptonic tag
 - ✓ inclusive tag

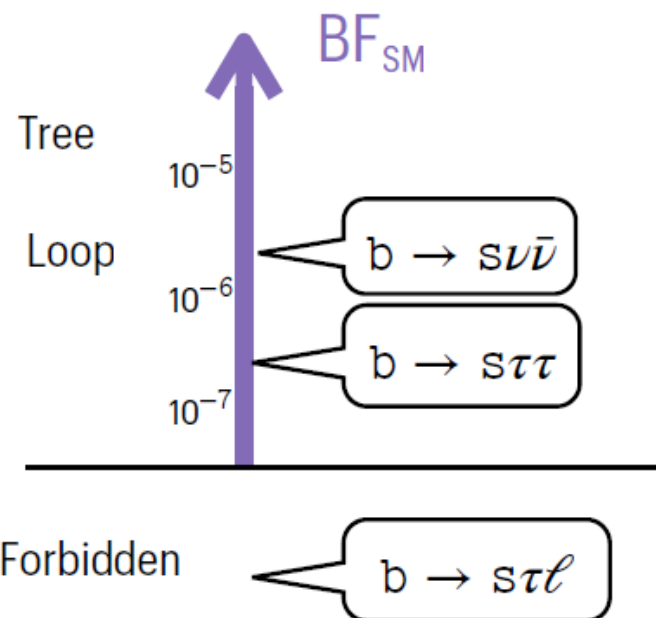
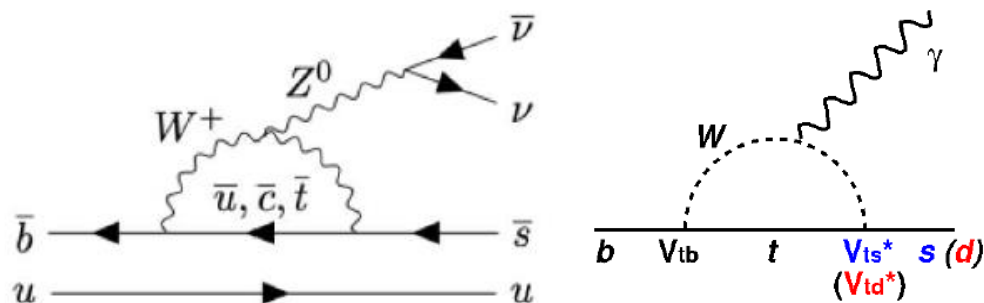
$$B \rightarrow Kvv, R(D^{(*)})$$

Electroweak Penguins

Electroweak Penguin Decays ($b \rightarrow s, d$)

- Flavor Changing Neutral Current (FCNC)

- ✓ Forbidden at the tree level in the SM.
- ✓ Small branching fraction (BF) in SM ($< 10^{-5}$)



- Sensitive to New Physics (NP).

- ✓ Unknown heavy particles in the loop.
- $b \rightarrow s\gamma, d\gamma, sl^+l^-, dl^+l^-, sv\bar{\nu}, \dots$
 - ✓ $b \rightarrow d\gamma$ is suppressed by $|V_{td}/V_{ts}|^2$ w.r.t. $b \rightarrow s\gamma$.
- Precise theoretical prediction for the inclusive process (e.g. $B \rightarrow X_s\gamma$).
- The branching fraction of exclusive processes (e.g. $B \rightarrow K^*\gamma$) has large uncertainty, except for $b \rightarrow sv\bar{\nu}$.

$$B(B^+ \rightarrow K^+ v\bar{\nu}) = (0.56 \pm 0.04) \times 10^{-5}$$

including $B^+ \rightarrow \tau^+(K^+\bar{\nu})\nu$ [\[PRD 107, 014511 \(2023\)\]](#)

$$B^+ \rightarrow K^+ \nu \bar{\nu}$$

Belle II Analysis with Run1 data (365 fb⁻¹)

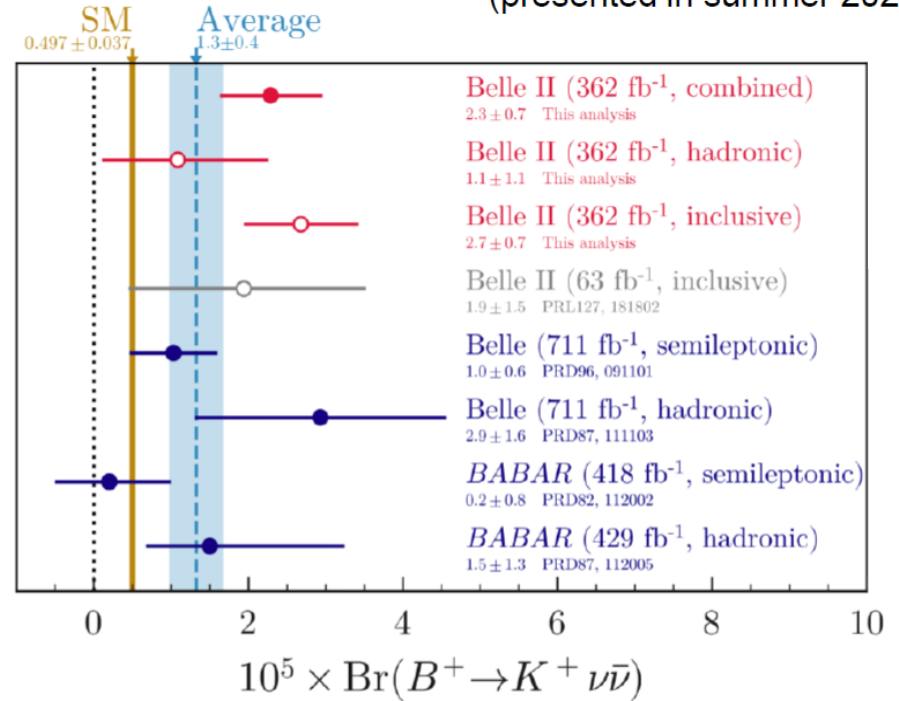
(presented in summer 2023)



[PRD 109, 112006 (2024)]

$$\mathcal{B}(B^+ \rightarrow K^+ \nu \bar{\nu}) = (2.3 \pm 0.5^{+0.5}_{-0.4}) \times 10^{-5}$$

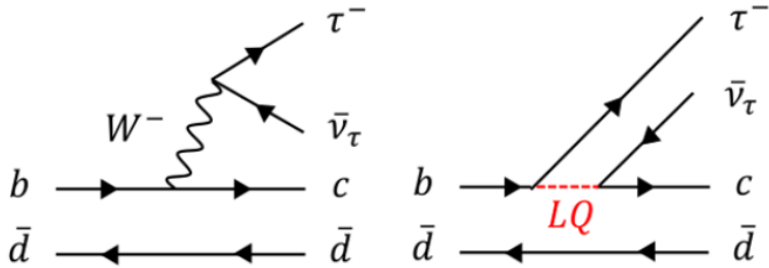
- Combined result from **Hadronic Tag Analysis (HTA)** and **Inclusive Tag Analysis (ITA)**.
- First evidence of the signal (3.5σ).
- 2.7σ deviation from the SM prediction.



The measured branching fraction assumes SM-only signal model.

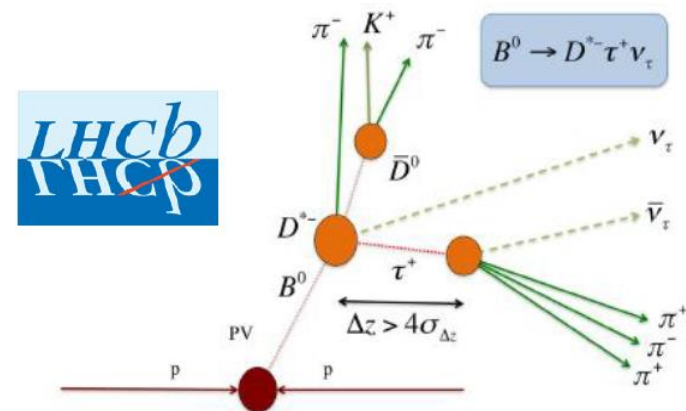
→ Belle II released full analysis likelihood for reinterpretation with other models: See [Phys. Rev. D 112, 092016](#) for demonstration and details.

$R(D^{(*)})$ - LFU in $B \rightarrow D^{(*)} l^+ \nu$



$$R(D^{(*)}) = \frac{\mathcal{B}(B \rightarrow D^{(*)} \tau \nu)}{\mathcal{B}(B \rightarrow D^{(*)} l \nu)} \quad (\ell = e \text{ or } \mu)$$

- In the SM, interaction does not depend on the flavor of the charged leptons.
 - ✓ The branching fractions differ due to the difference of the charged lepton mass (phase space, helicity suppression).
- $R(D^{(*)})$ is well predicted in the SM: $R(D)=0.30$, $R(D^*)=0.25$
- A longstanding tension between the theory and the experiment: “B anomaly”
 - ✓ Contribution from NP (charged Higgs, leptoquarks....) ?
- Experimental techniques:
 - ✓ Tag one of the two B mesons (Belle II)
 - ✓ τ vertex detached from B vertex (LHCb)
 - ✓ Multiple analyses using different τ decay modes and tag methods.



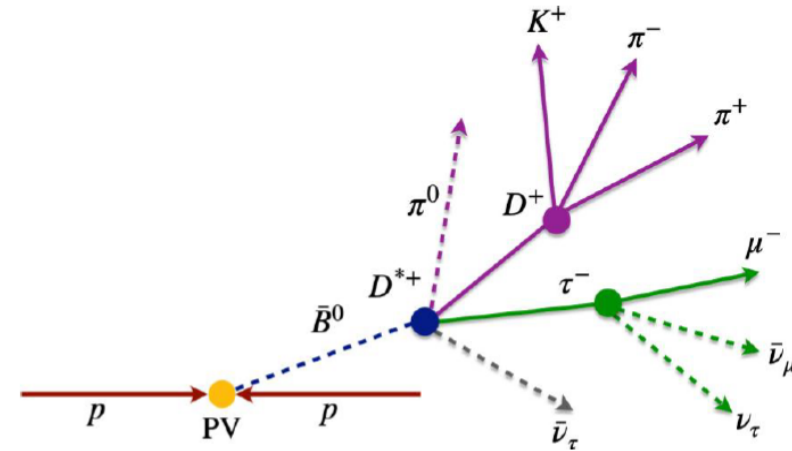
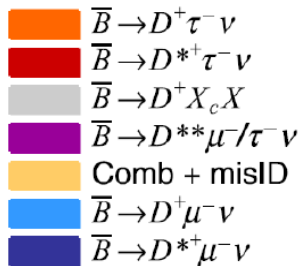
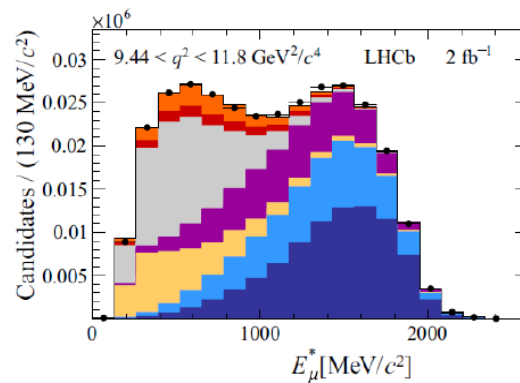
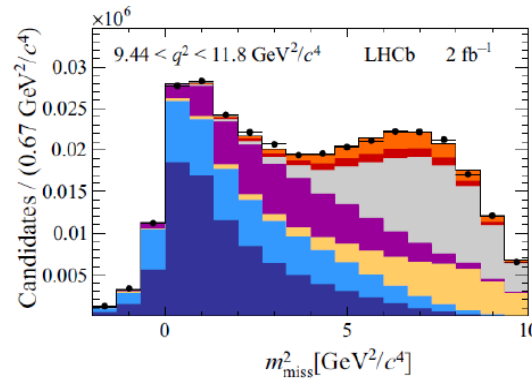
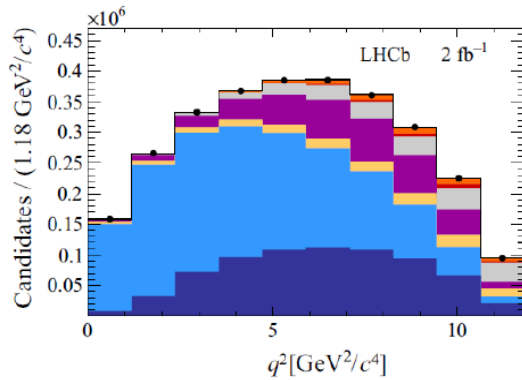
Results on $R(D^{(*)})$ from LHCb

$R(D^{(*)+})$ with muonic τ decay by LHCb (2 fb^{-1})

[PRL 134, 061801 (2025)]



- Simultaneous measurements of $\bar{B}^0 \rightarrow D^+ \tau^- \nu$ and $\bar{B}^0 \rightarrow D^{*+} (\rightarrow D^+ \pi^0) \tau^- \nu$.
- Same final states for the signal and the normalization ($\bar{B}^0 \rightarrow D^{(*)+} \mu^- \nu$)
- No τ vertex.



$$R(D^+) = 0.249 \pm 0.043 \pm 0.047,$$

$$R(D^{*+}) = 0.402 \pm 0.081 \pm 0.085,$$

(stat.) (syst.)

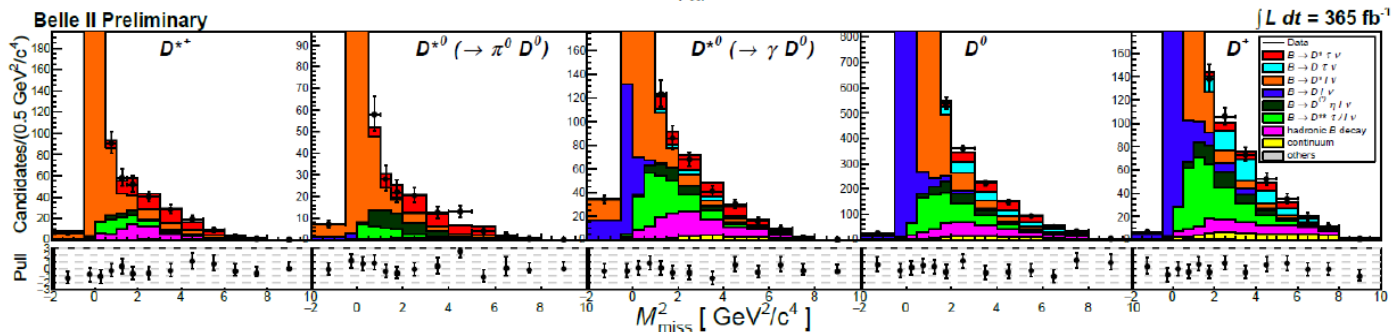
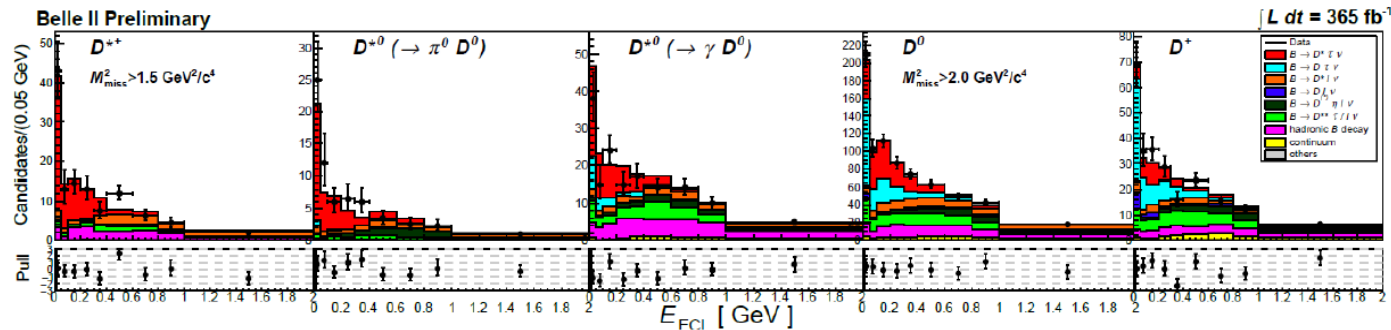
Results on $R(D^{(*)})$ from Belle II



Two Belle II results on $R(D^{(*)})$ (365 fb^{-1})

- Semi-leptonic tag + leptonic τ decay [[PRD D 112, 032010 \(2025\)](#)]
- Hadronic tag + leptonic τ decay [presented at CKM2025] → shown in this page

2D binned template likelihood fit in E_{ECL} (residual energy in the calorimeter) and missing mass squared, simultaneously in 5 channels.



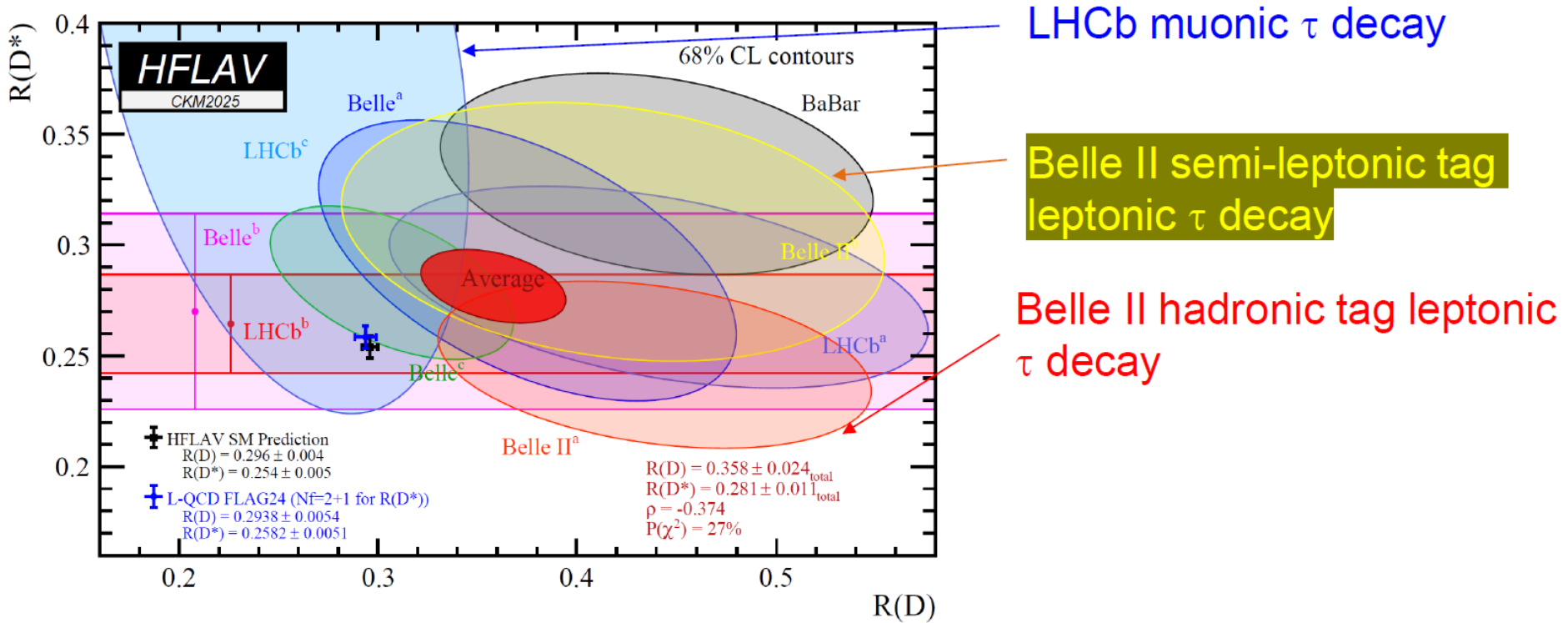
- $\bar{B}^0 \rightarrow D^{*+} \tau^- \nu$
- $B^- \rightarrow D^{*0} (\rightarrow D^0 \pi^0) \tau^- \nu$
- $B^- \rightarrow D^{*0} (\rightarrow D^0 \gamma) \tau^- \nu$
- $B^- \rightarrow D^0 \tau^- \nu$
- $\bar{B}^0 \rightarrow D^+ \tau^- \nu$

$$R(D^*) = 0.242 \pm 0.019 \text{ (stat.)} \pm 0.016 \text{ (syst.)}$$

$$R(D) = 0.439 \pm 0.055 \text{ (stat.)} \pm 0.046 \text{ (syst.)}$$

Most precise measurement with hadronic-tag.

$R(D^{(*)})$ - LFU in $B \rightarrow D^{(*)} l^+ \nu$



3.8 σ tension with SM prediction!

- $R(D)$ tension with SM: 2.5 σ
- $R(D^*)$ tension with SM: 2.3 σ

CP Violation

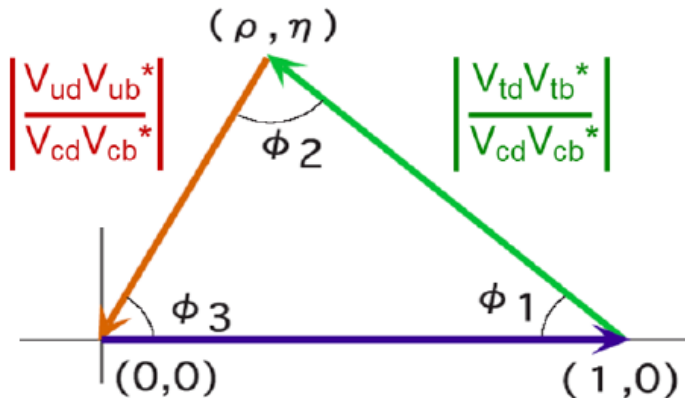
CP Violation and KM Theory

- 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

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

Triangles in the complex plane (from Unitarity)



- Time dependent asymmetry
 - ✓ Asymmetric energy of e^+e^- collider (BaBar, Belle (II)).
 - ✓ High boost in hadron colliders.

Time Dependent CP Asymmetry in B decays

Mixing-induced CP asymmetry of B mesons

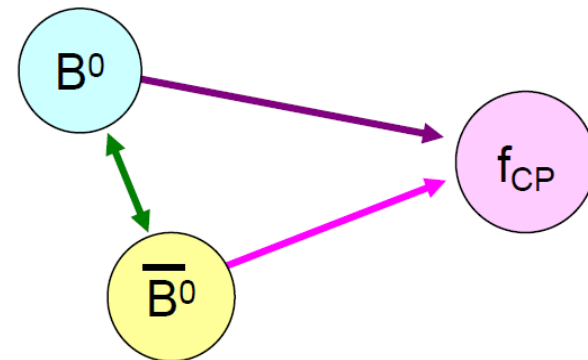
- B^0 and \bar{B}^0 decay to a common CP eigenstate f_{CP} .
- CP violation appears as a decay time difference.

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

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

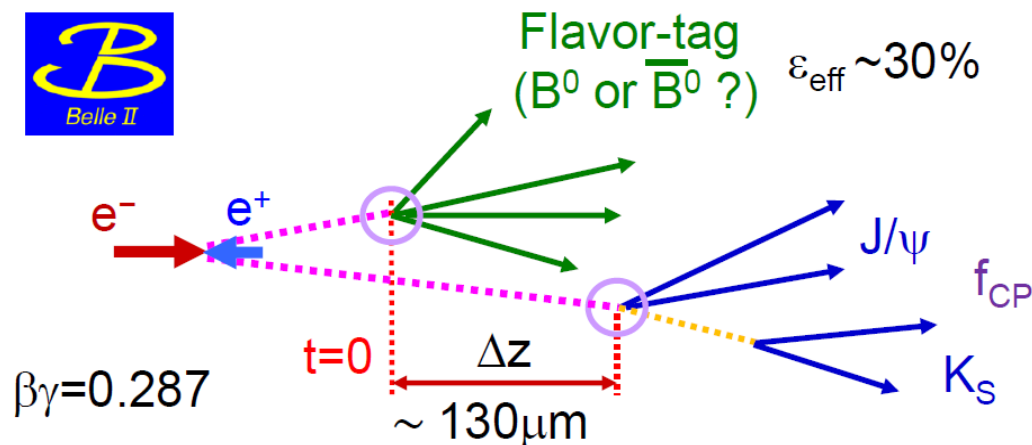
$$S = -\xi \sin(2\phi_1) \text{ for } B \rightarrow J/\psi K_S$$

$$\phi_1 = \beta$$

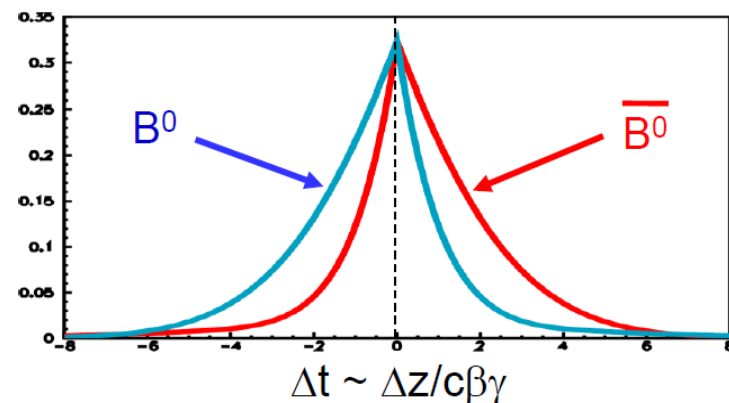


S : mixing induced CPV

C : direct CPV (= -A)

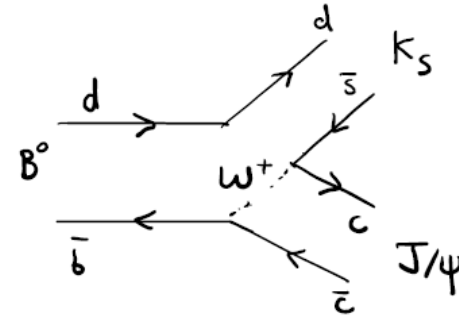


measure position instead of time



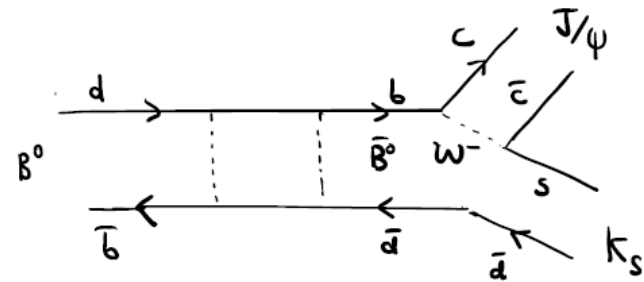
Time Dependent CP Asymmetry at B factories

Golden measurement channel $B_d \rightarrow J/\psi K_S$
 tree dominated $b \rightarrow c\bar{c}s$ transition



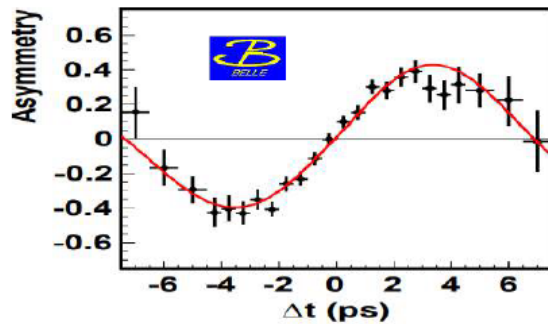
Measurement primary goal of the b-factories

Interference between decays with and
 and without mixing leads to CP asymmetry



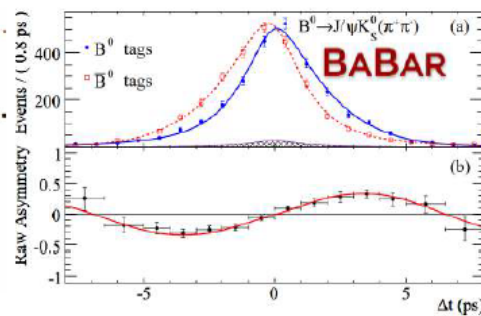
$$A_{CP}(t) = -\eta_f \sin 2\beta \sin(\Delta m_d t)$$

$$\sin 2\phi_1 = 0.667 \pm 0.023 \pm 0.012$$

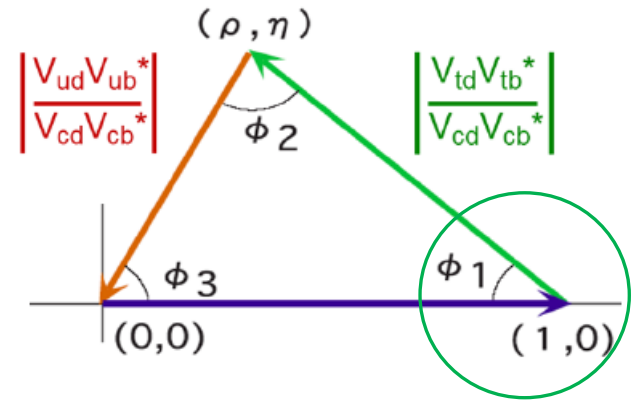


PRD 79 (2009) 072009

$$\sin 2\beta = 0.687 \pm 0.028 \pm 0.012$$



PRL 108 (2012) 171802

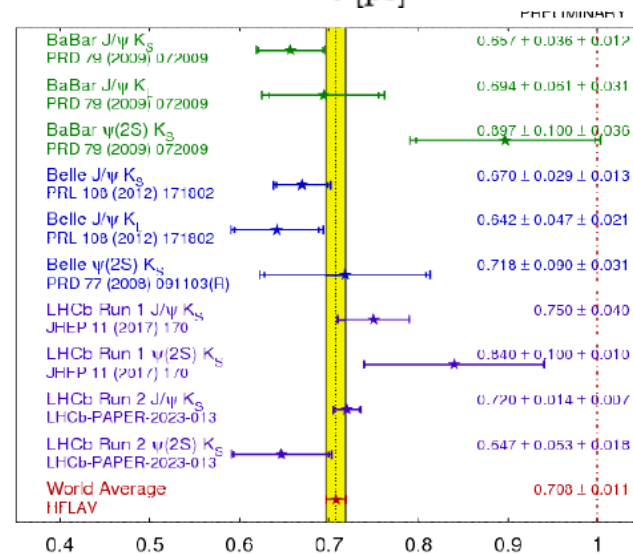
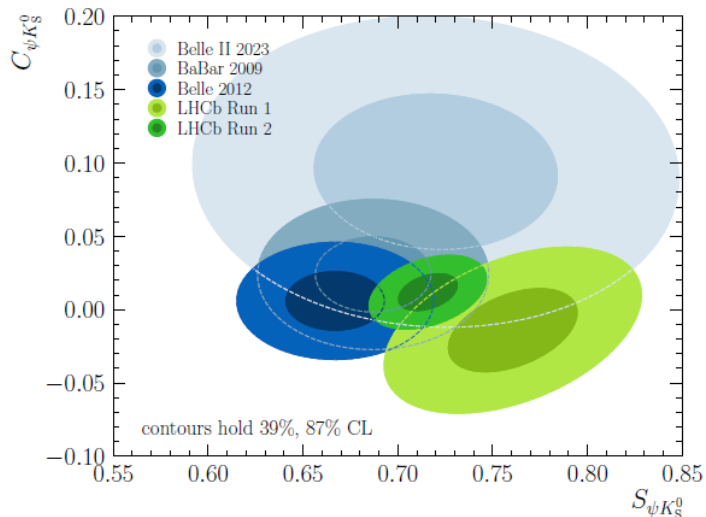
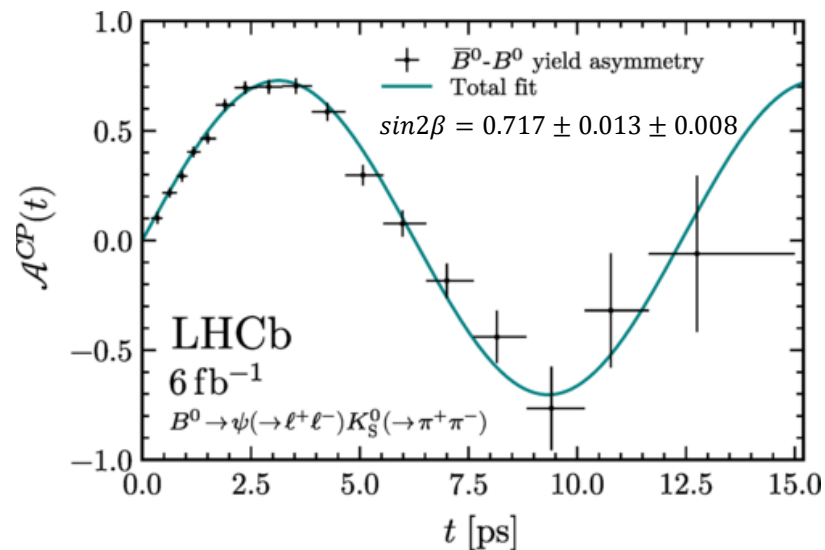
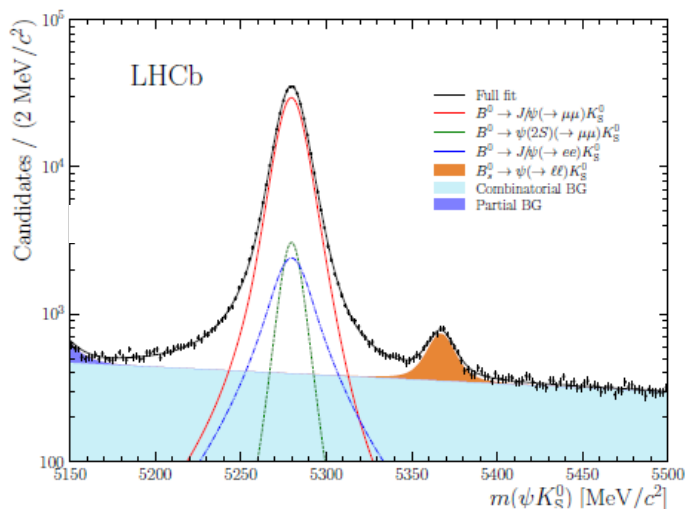


Time Dependent CP Asymmetry at LHCb

New LHCb Run 2 (6 fb⁻¹) results using $B_d \rightarrow J/\psi K_S$ (both muons and electrons) and $B_d \rightarrow \psi(2S)K_S$

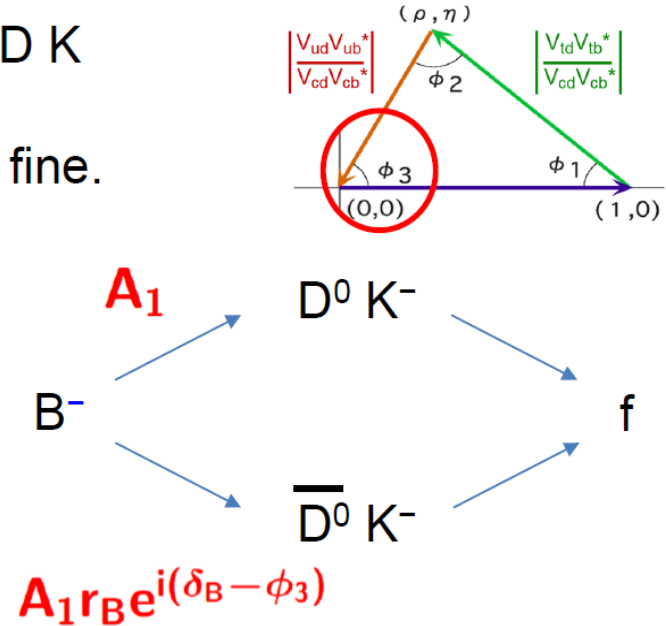
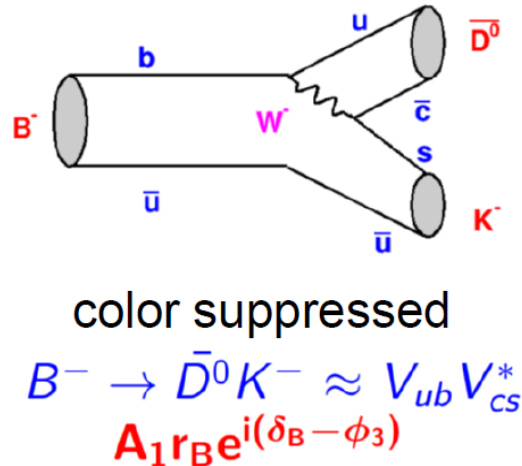
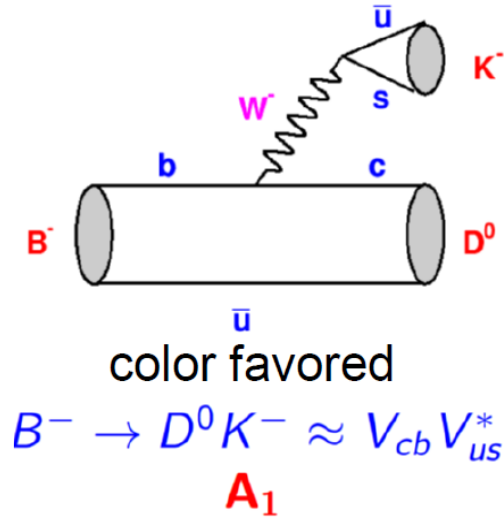
Tagged time dependent analysis to determine $\sin 2\beta$

PRL132(2024)021801



Direct CP Asymmetry and ϕ_3/γ measurement

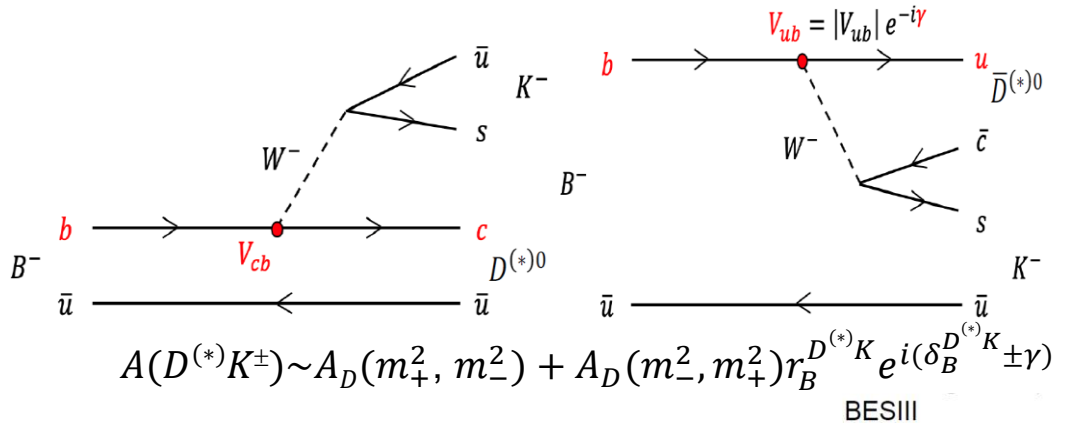
- γ / ϕ_3 can be measured using the interference $B \rightarrow D K$ and $B \rightarrow \bar{D} K$.
 - ✓ Other modes like $B \rightarrow D K^*$, $B \rightarrow D \pi$ etc. are fine.



- 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.

ϕ_3/γ Measurements

- CKM γ can be measured directly with negligible theoretical uncertainty.



Several time-independent modes:

$B^\pm \rightarrow D^{(*)}h^\pm$, D^0 and \bar{D}^0 decay to the same final state.

- GLW: CP eigenstates ($D \rightarrow K^+K^-/\pi^+\pi^-$).
- ADS: Cabibbo-favoured (CF) or Cabibbo-suppressed (CS) decays ($D \rightarrow K^+\pi^-$).
- BPGGSZ: multi-body D decays, study CP asymmetry over phase space ($D \rightarrow K_S^0\pi^+\pi^-$).

• Signal yields in each bin (i) related with CP observables

$$N_i^- \propto (F_i + (x_-^2 + y_-^2)F_{-i} + 2\sqrt{F_i F_{-i}}(c_i x_- + s_i y_-))$$

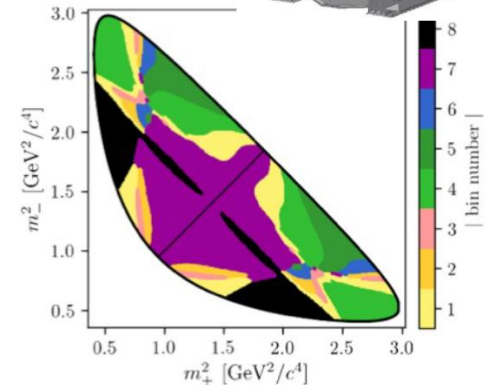
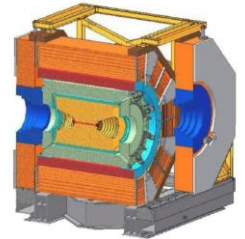
$$N_i^+ \propto (F_{-i} + (x_+^2 + y_+^2)F_i + 2\sqrt{F_i F_{-i}}(c_i x_+ - s_i y_+))$$

F_i : fractional yields of D in bin i

c_i, s_i : the cosine and sine of the strong phase difference of $D^0 - \bar{D}^0$ decay in bin i .

$$r_B^{D^{(*)}K} e^{i(\delta_B^{D^{(*)}K} \pm \gamma)} = x_\pm + iy_\pm$$

input from BESIII and CLEO-c.

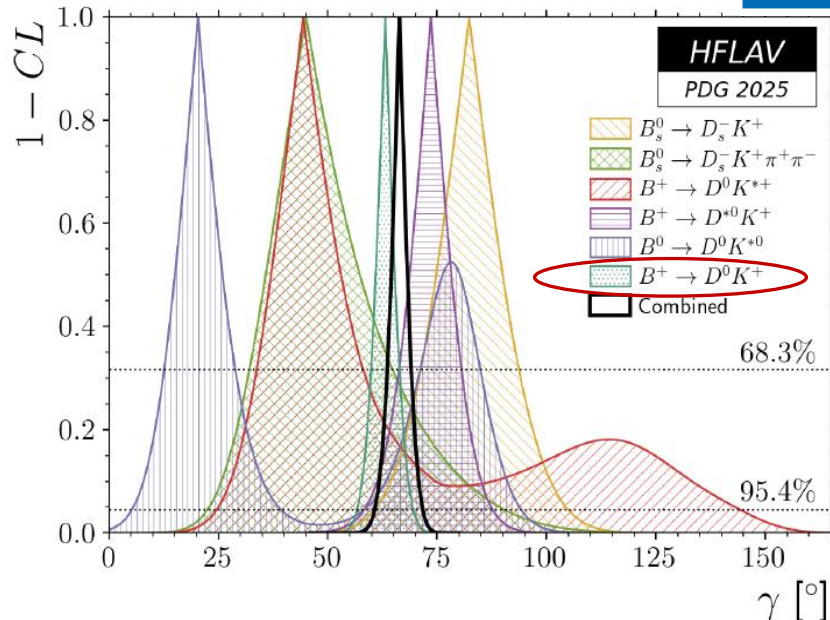
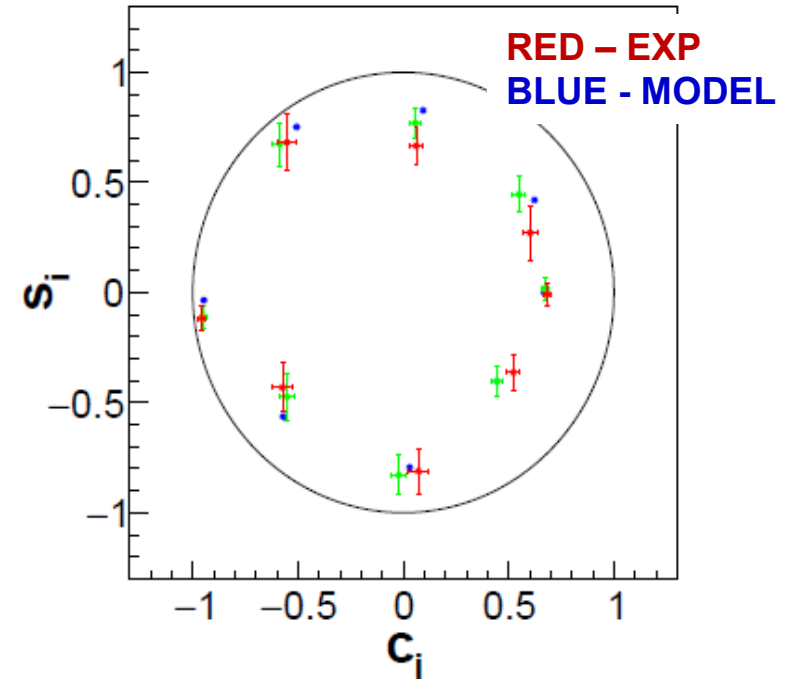


ϕ_3/γ Measurements

- Several methods (GLW, ADS, BPGGSZ, GLS) using different decays.
- In the method with multi-body D decays, D decay parameters (information on the strong phase) are necessary inputs from CLEO-c, BESIII.
- World average of measurements:
 3° precision
 ✓ Dominated by LHCb.



BES III PRD 112 (2025) 1, 012015



$$\gamma = (66.4^{+2.7}_{-2.8})^\circ$$

(HFLAV)

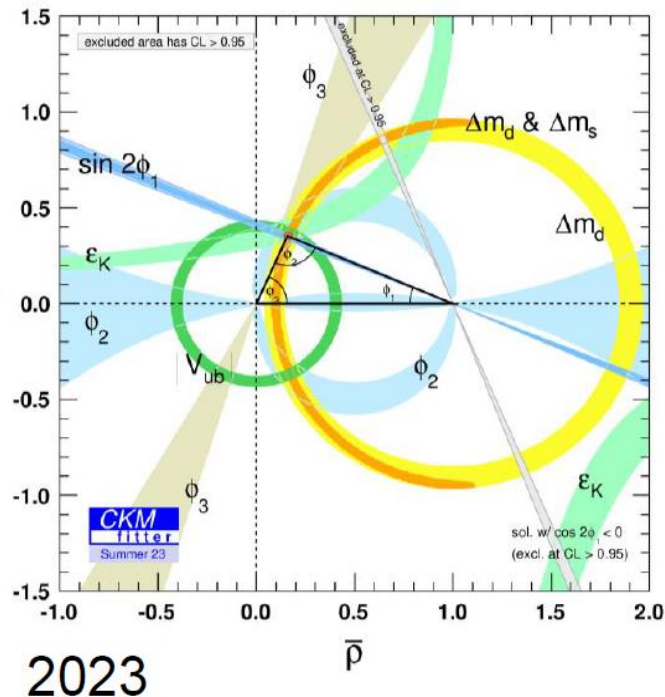
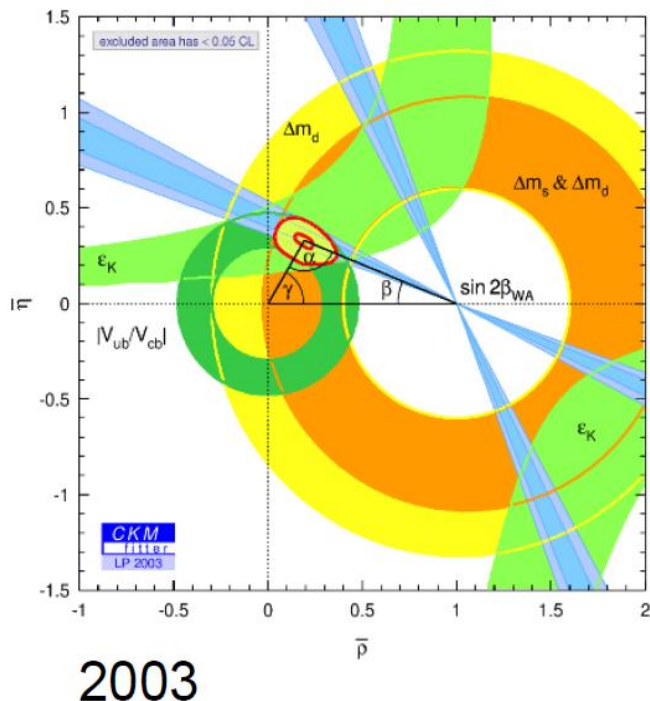
Global fit by CKM fitter (2023)

$$\gamma = (65.2 \pm 1.5)^\circ$$

Unitarity Triangle

Unitarity Triangle

- Precise measurement of the Unitarity Triangle \rightarrow Test of the SM
 - ✓ “Over-constrain” the triangle.

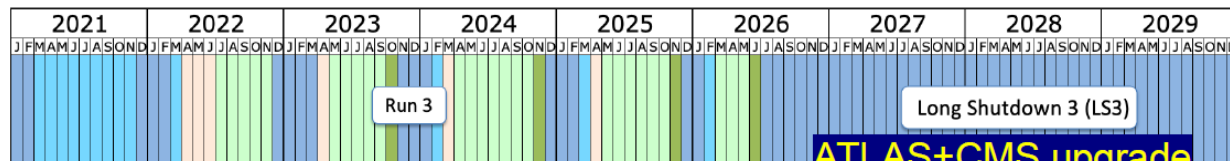


ϕ_1	$=$	β
ϕ_2	$=$	α
ϕ_3	$=$	γ

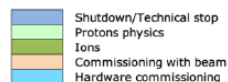
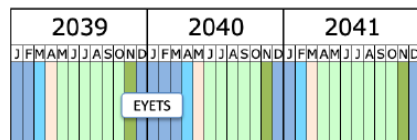
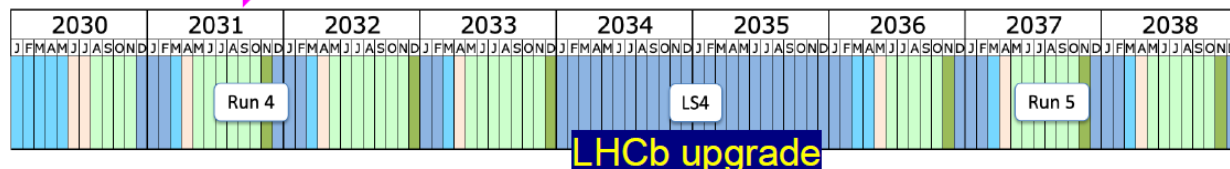
- Combinations of many measurements by various experiments.
- Other triangles (hence parameters) exists.

Future Plans

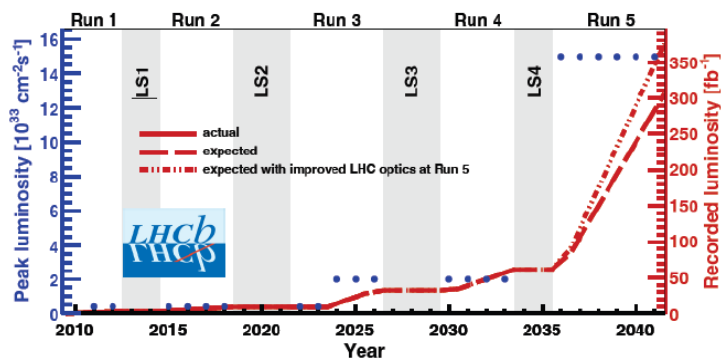
LHC schedule



HL-LHC

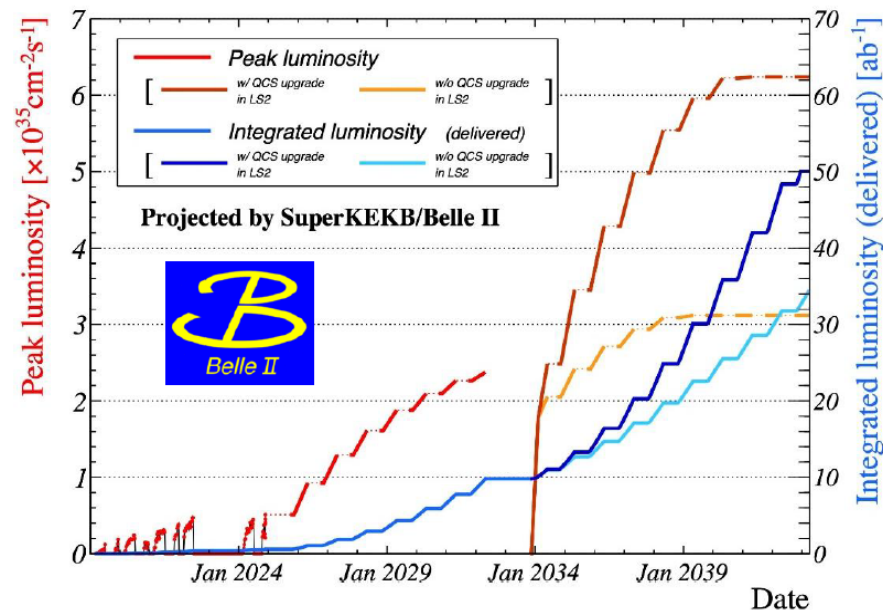


Last update: November 24



- 50 fb^{-1} by 2033 and $> 300 \text{ fb}^{-1}$ by 2041

- $30\text{-}50 \text{ ab}^{-1}$ by 2040s



Prospects for UT Constraints

- Many exciting new experimental measurements with high statistics datasets
- Precision improving as datasets grow
- Novel techniques leveraging differential measurements and full angular dependence
- Significant work ongoing on theory side as well!

Adapted from [arXiv:2208.05403](https://arxiv.org/abs/2208.05403)

Observable	Current best	Belle II		LHCb		ATLAS	CMS	BESIII	STCF
		50 ab ⁻¹	250 ab ⁻¹	50 fb ⁻¹	300 fb ⁻¹	3 ab ⁻¹	3 ab ⁻¹	20 fb ⁻¹ (*)	1 ab ⁻¹ (*)
CKM tests and CP violation									
α	5° [60]	0.6°	0.3°						
$\sin 2\beta(B^0 \rightarrow J/\psi K_S^0)$	0.029 [61]	0.005	0.002	0.006	0.003				
γ	4° [62]	1.5°	0.8°	1°	0.35°			0.4° (†)	< 0.1° (†)
$\phi_s(B_s^0 \rightarrow J/\psi \phi)$	32 mrad [63]			10 mrad	4 mrad	4–9 mrad	5–6 mrad		
$ V_{ub} (B^0 \rightarrow \pi^- \ell^+ \nu)$	5% [64, 65]	2%	< 1%	na	na				
$ V_{ub} / V_{cb} (A_b^0 \rightarrow p \mu^- \bar{\nu})$	6% [66]			2%	1%				
$f_{D^+} V_{cd} (D^+ \rightarrow \mu^+ \nu)$	2.6% [67]	1.4%	na					1.0%	0.15%
$S_{CP}(B^0 \rightarrow \eta' K_S^0)$	0.08 [68, 69]	0.015	0.007	na	na				
$A_{CP}(B^0 \rightarrow K_S^0 \pi^0)$	0.15 [68, 70]	0.025	0.018	na	na				
$A_{CP}(D^+ \rightarrow \pi^+ \pi^0)$	11×10^{-3} [71]	1.7×10^{-3}	na	na	na			na	na
$\Delta x(D^0 \rightarrow K_S^0 \pi^+ \pi^-)$	18×10^{-5} [72]	na	na	4.1×10^{-5}	1.6×10^{-5}				
$A_{\Gamma}(D^0 \rightarrow K^+ K^-, \pi^+ \pi^-)$	11×10^{-5} [73]	na	na	3.2×10^{-5}	1.2×10^{-5}				

61: PRL 108 (2012) 171802
 62: JHEP 12 (2021) 141
 63: EPJC 79 (2019) 706

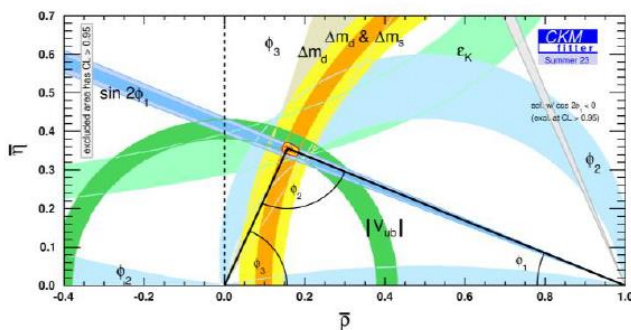
64: PRD 83 (2011) 032007
 65: PRD 83 (2011) 071101
 66: Nature Phys 11 (2015) 743

67: PRD 89 (2014) 051104
 68: PRD 79 (2009) 052003
 69: JHEP 10 (2014) 165

70: PRD 81 (2010) 011101
 71: JHEP 06 (2021) 019
 72: PRL 127 (2021) 111801

Summary and Conclusion

- Flavor physics experiments: search for NP with precise measurements.
 - ✓ LHCb, ATLAS, CMS, Belle II, BESIII.
 - ✓ Producing many new results.
- $B \rightarrow K_{VV}, R(D^{(*)})$: tension from the SM prediction?
- Precision measurement of CKM matrix elements.
- One order larger dataset in future.



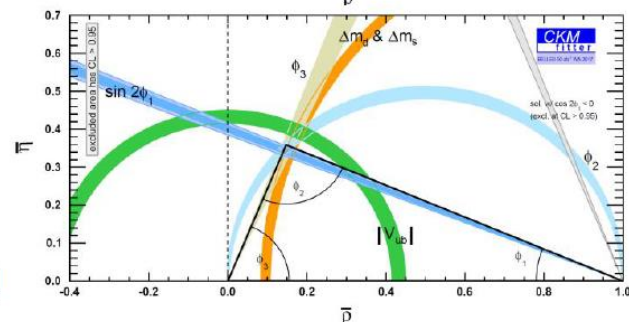
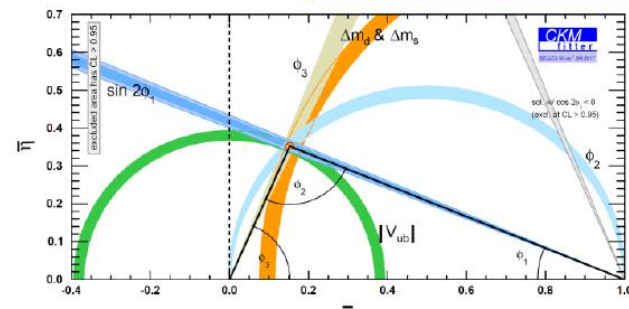
consistent



inconsistent



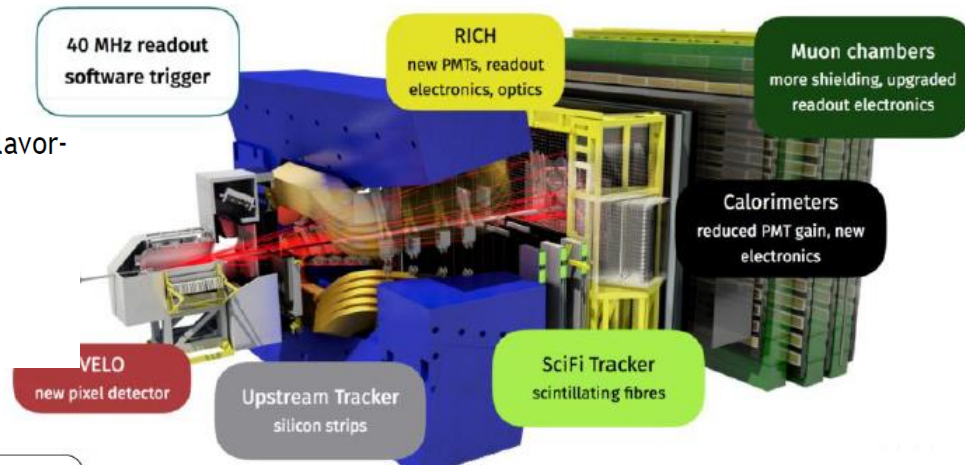
[PTEP (2019) 123C01]



Backup

CKM matrix is a 3×3 unitary matrix, elements represent the strength of flavor-changing weak interactions.

$$\begin{bmatrix} d' \\ s' \\ b' \end{bmatrix} = V_{CKM} \begin{bmatrix} d \\ s \\ b \end{bmatrix}, \text{ where } V_{CKM} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$



The Belle II detector

Vertex detector (VXD)

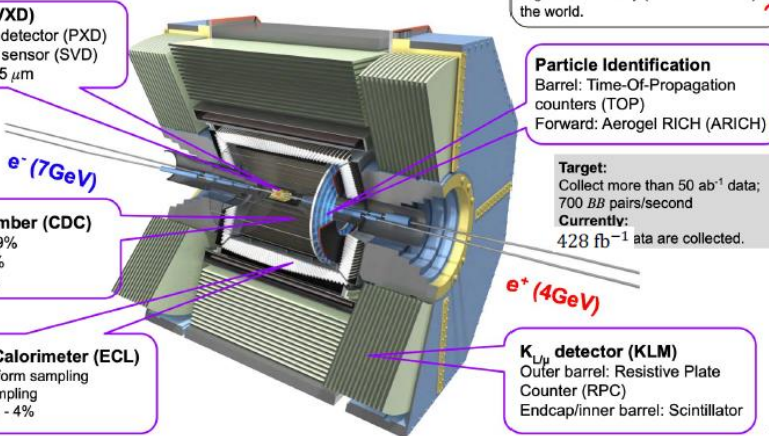
Inner 2 layers: pixel detector (PXD)
Outer 4 layers: strip sensor (SVD)
Vertex resolution : $15 \mu\text{m}$

Central Drift Chamber (CDC)

Track efficiency ~ 99%
 dE/dx resolution : 5%
 p_T resolution : 0.4 %

ElectroMagnetic Calorimeter (ECL)

Barrel: CsI(Tl) + waveform sampling
Endcap: waveform sampling
Energy resolution : 1.6 - 4%



Features:
Energy-asymmetric e^+e^- collider \rightarrow low background.
Highest luminosity ($3.1 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$) in the world.

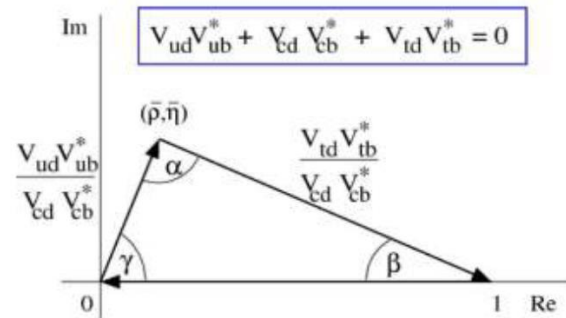
Particle Identification
Barrel: Time-Of-Propagation counters (TOP)
Forward: Aerogel RICH (ARICH)

Target:
Collect more than 50ab^{-1} data;
700 BB pairs/second
Currentiv:
 428fb^{-1} data are collected.

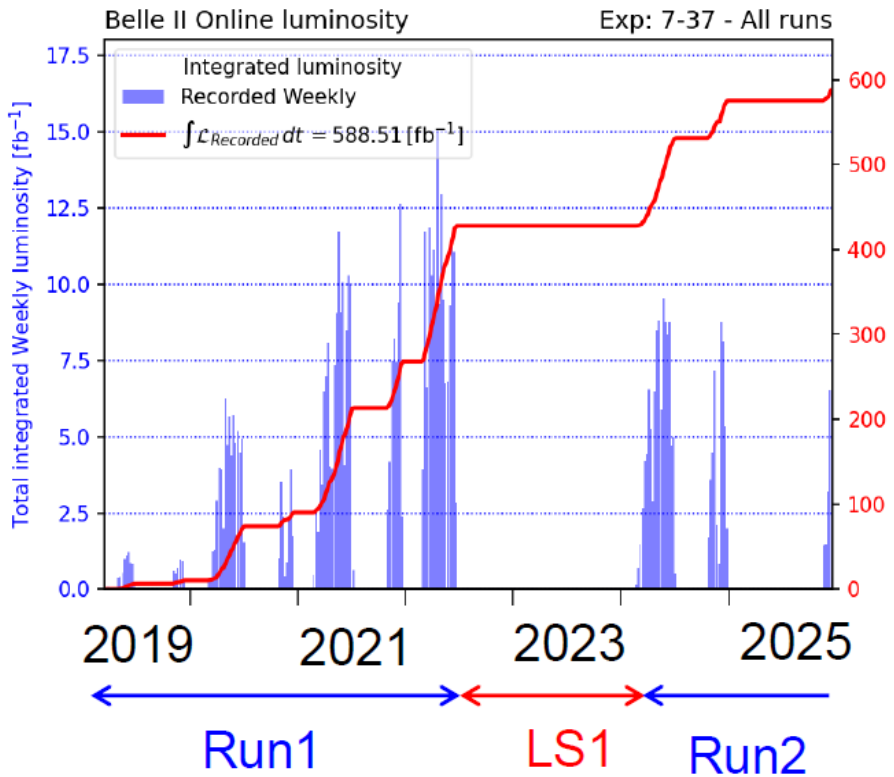
K_{Lp} detector (KLM)
Outer barrel: Resistive Plate Counter (RPC)
Endcap/inner barrel: Scintillator

Belle II TDR: arXiv:1011.0352

$$V_{CKM} = \begin{pmatrix} 1 - \frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$



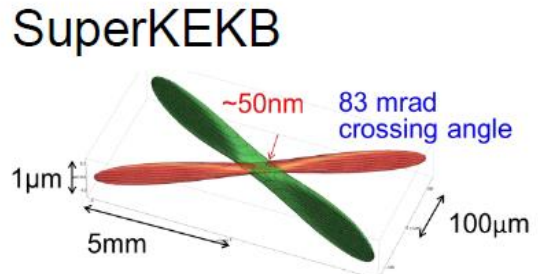
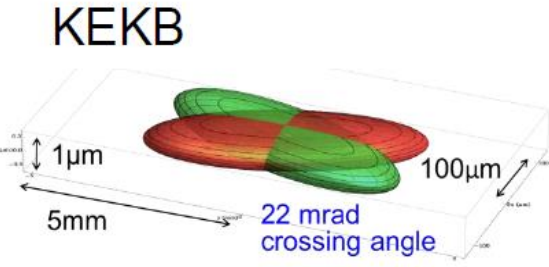
- Luminosity (\sim intensity) is a key for the experiment.
 - ✓ Luminosity [$\text{cm}^{-2} \text{s}^{-1}$] = (event rate [s^{-1}]) / (cross-section [cm^{-2}])
 - ✓ Integrated luminosity = Luminosity \times (operation time) : collected data size



- Luminosity $5.1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ achieved (Dec. 2024):
 - ✓ World record ($\sim \times 2.5$ of KEKB)
 - ✓ Aiming one order higher.
- 590 fb^{-1} of data accumulated so far.
 - ✓ Similar to BaBar data set.
 - ✓ Belle: 1 ab^{-1} ($=1000 \text{ fb}^{-1}$) in 11 years.
- Belle II target: 50 ab^{-1}
- Run 2 started in 2024.
- 2025 operation started in November.

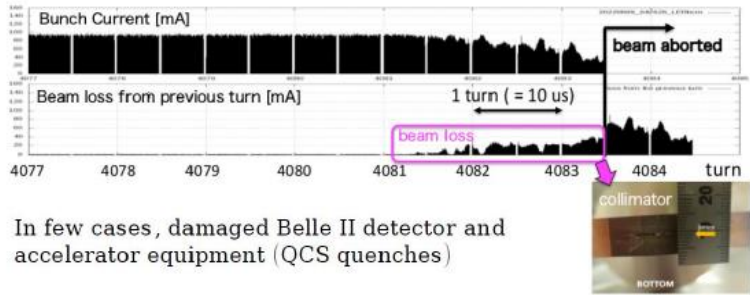
Long shutdown to fully install PXD detector

nano beam scheme: new technology



An issue in SuperKEKB: Sudden Beam Loss (SBL)

- All the beam is lost within a few turns.

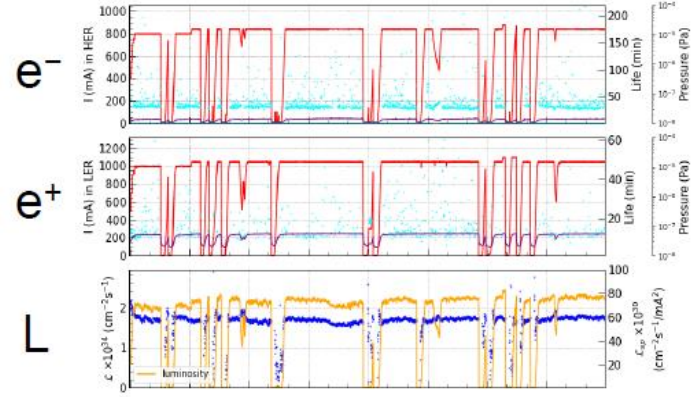


In few cases, damaged Belle II detector and accelerator equipment (QCS quenches)

- It is turned out that most SBLs were caused from some vacuum sealing materials in SuperKEKB. → clean up was done in 2025.
- The issue of SBL seems to be mostly solved !

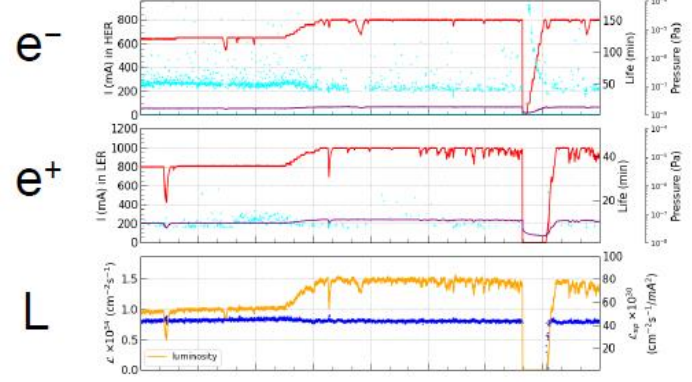
2024/11/3

11/02 23:57:56 - 11/03 23:57:56, 2024 JST
 $C_{peak} 2.470 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$ @ 18:56:33 11/03
 HER $I_{peak} 880 \text{ mA}$ $n_b 2346$ β_x^*/β_y^* 60 / 1 mm
 int. $L/day 1235 / 1335 \text{ pb}^{-1}$
 LER $I_{peak} 1100 \text{ mA}$ $n_b 2346$ β_x^*/β_y^* 80 / 1 mm



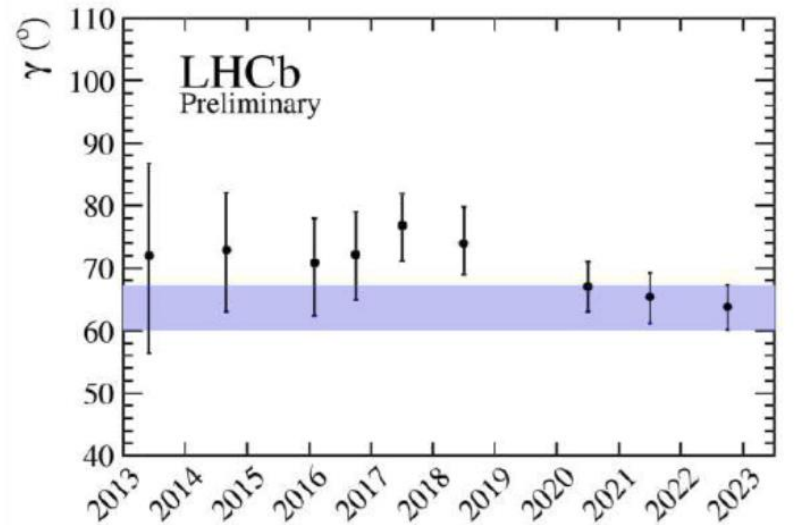
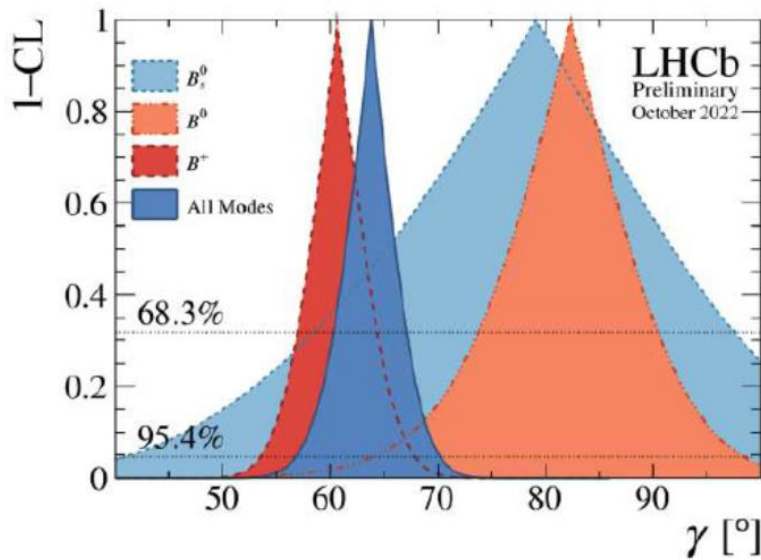
2025/12/1

12/01 08:59:24 - 12/02 08:59:24, 2025 JST
 $C_{peak} 1.569 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ @ 01:27:36 12/02
 HER $I_{peak} 800 \text{ mA}$ $n_b 2346$ β_x^*/β_y^* 60 / 1 mm
 int. $L/day 346 / 384 \text{ pb}^{-1}$
 LER $I_{peak} 1000 \text{ mA}$ $n_b 2346$ β_x^*/β_y^* 60 / 1 mm



angle γ

Combined fit to all LHCb measurements and charm mixing data



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

Consistent with the CKMFitter prediction

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

Prospects for γ

2023

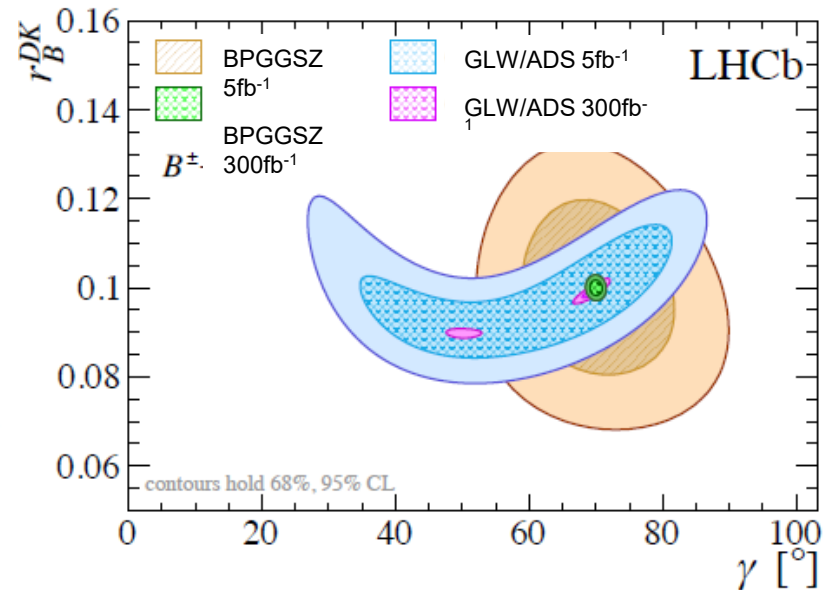
At present $\sigma_\gamma \sim 4^\circ$

2030

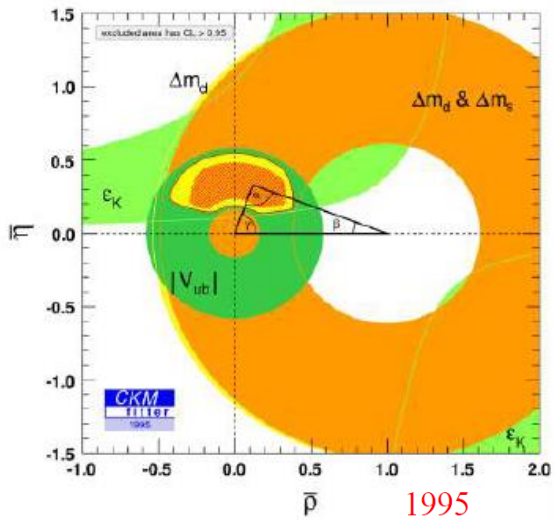
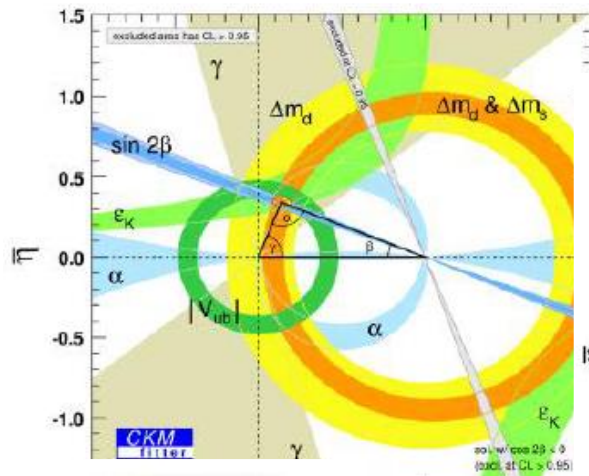
Belle 2 with 50 ab^{-1} $\sigma_\gamma \sim 1 - 2^\circ$
LHCb Upgrade I (50 fb^{-1}) $\sigma_\gamma \sim 1^\circ$

2040

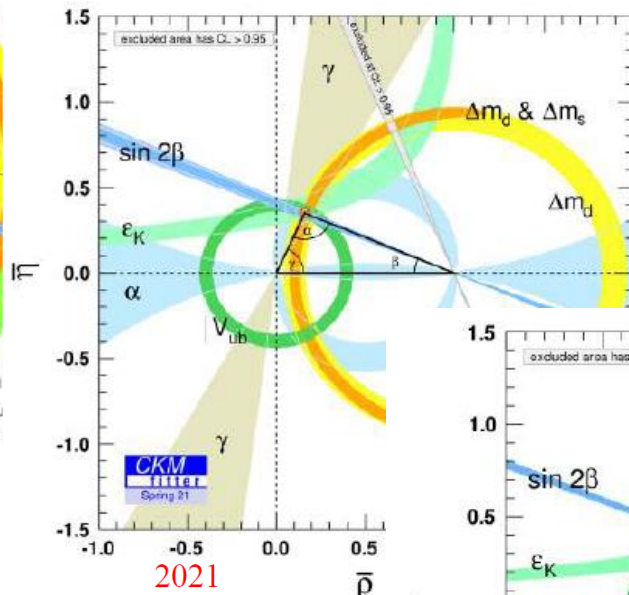
LHCb Upgrade II (300 fb^{-1}) $\sigma_\gamma \sim 0.4^\circ$



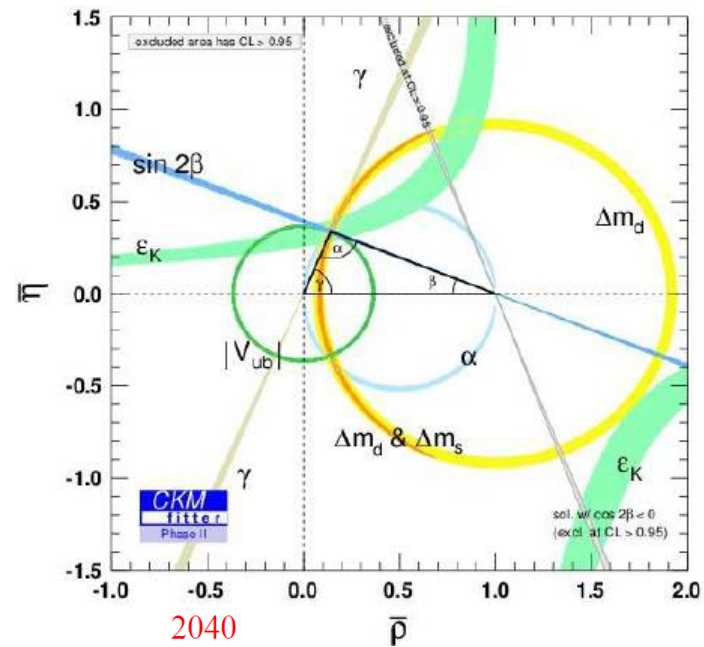
To fully exploit precision improved measurements of strong phases from Super Charm Tau Factory



2009



2021



2040