High Statistics B Decays

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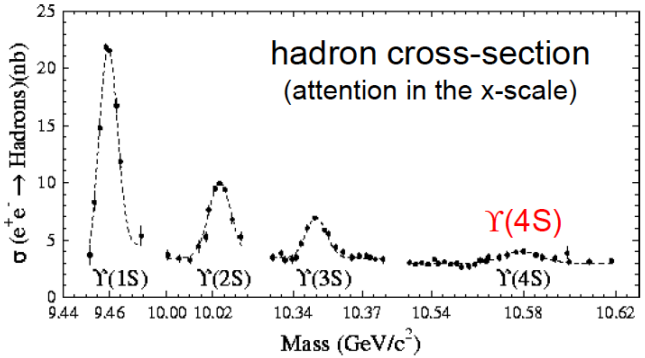
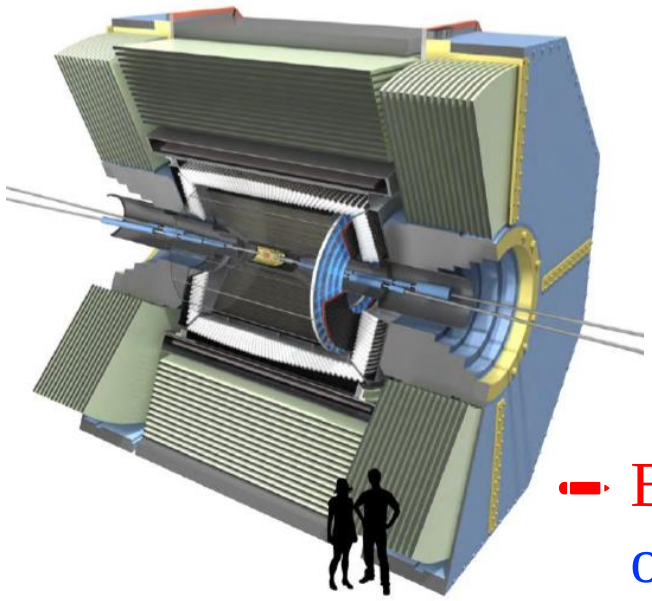
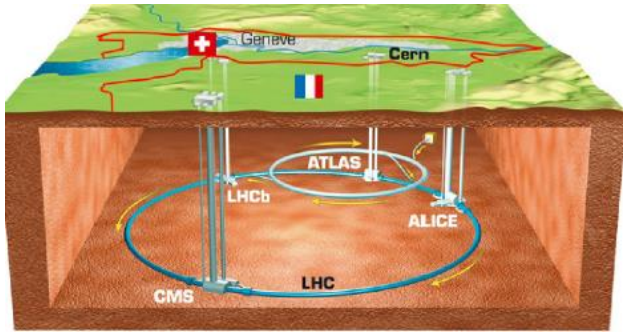
Tao Luo

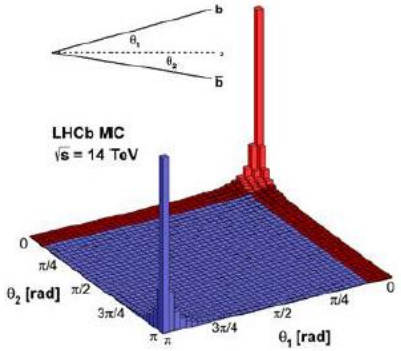
Story of two players...

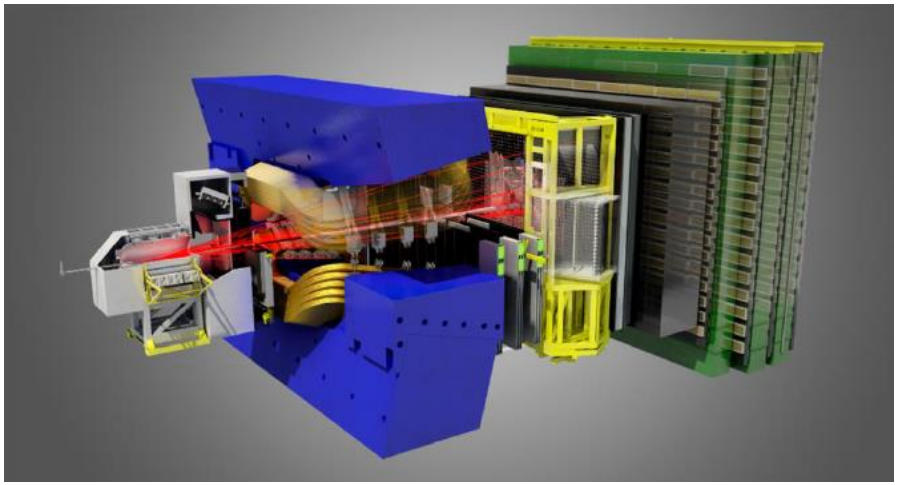




- LHCb: a general-purpose spectrometer in the forward direction at the LHC, optimized for precision flavor physics



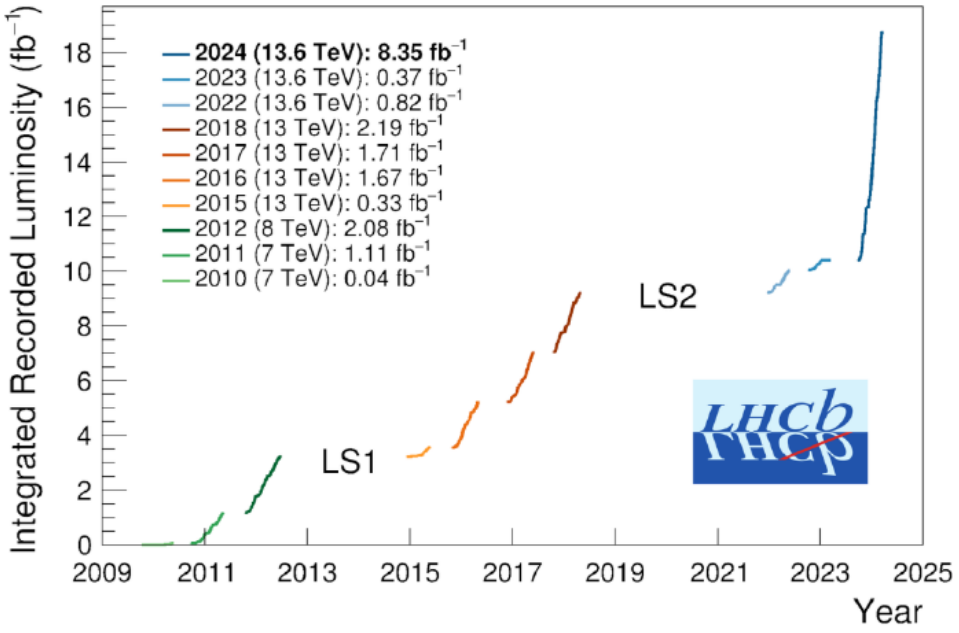




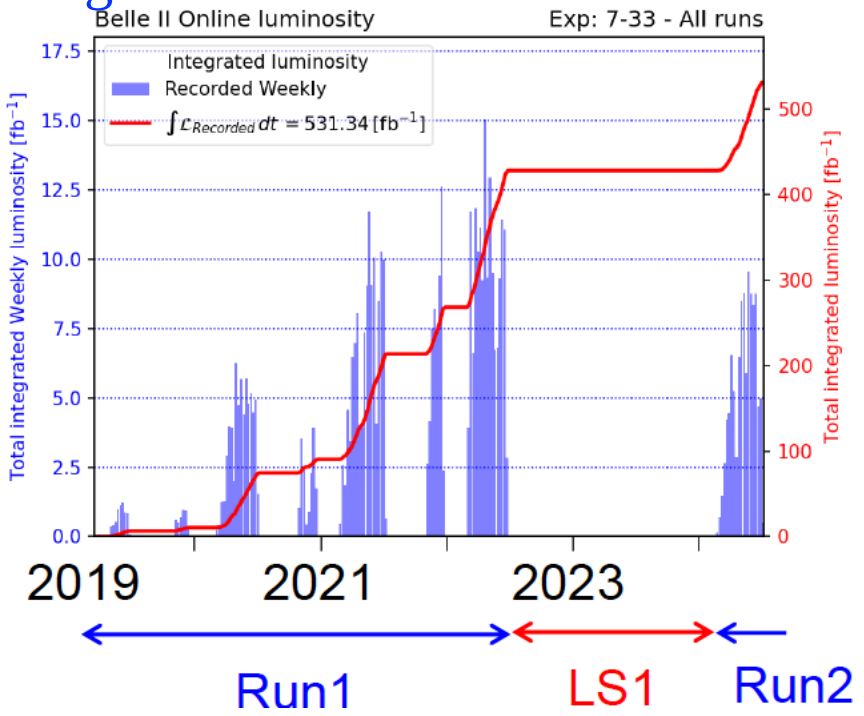
- Belle II: second-generation e^+e^- flavor factory operating near the $\Upsilon(4S)$ resonance

In their kitty, they have got

- Integrated luminosity: 9 fb^{-1} of pp collisions (+ pPb, PbPb, fixed target mode)
- So far, about 8 fb^{-1} in 2024



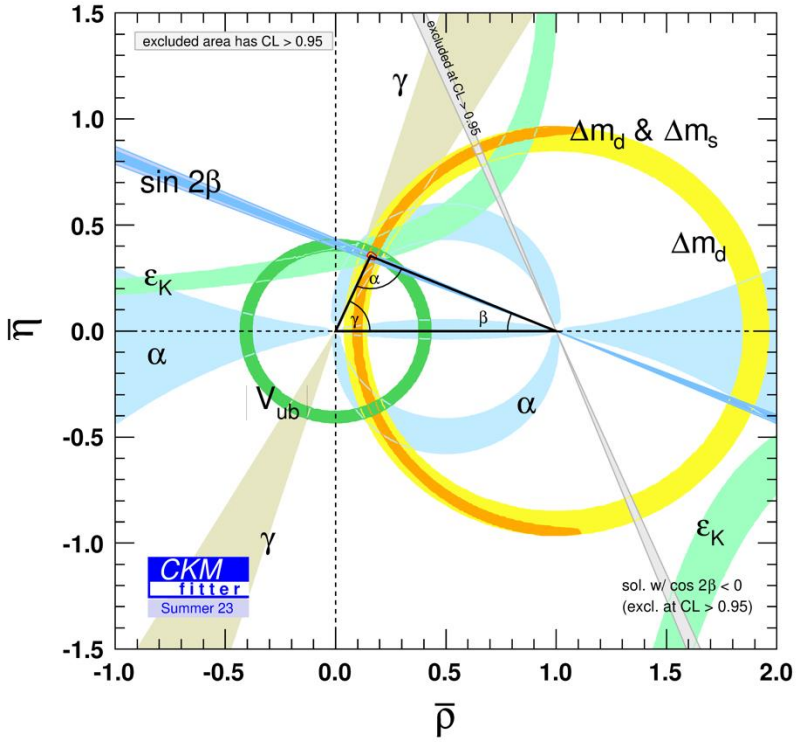
- Peak luminosity: 4.7 × $10^{34} cm^{-2} s^{-1}$
  - World record (~ × 2 of KEKB)
  - Aiming an order higher
- Integrated luminosity: 530 fb^{-1}
  - Similar to BABAR data set and half of what Belle recorded in 11 years
- Target: 50 ab^{-1}



➡ Roughly, 1 fb^{-1} of LHCb corresponds to 1 ab^{-1} of Belle II

Their main goals

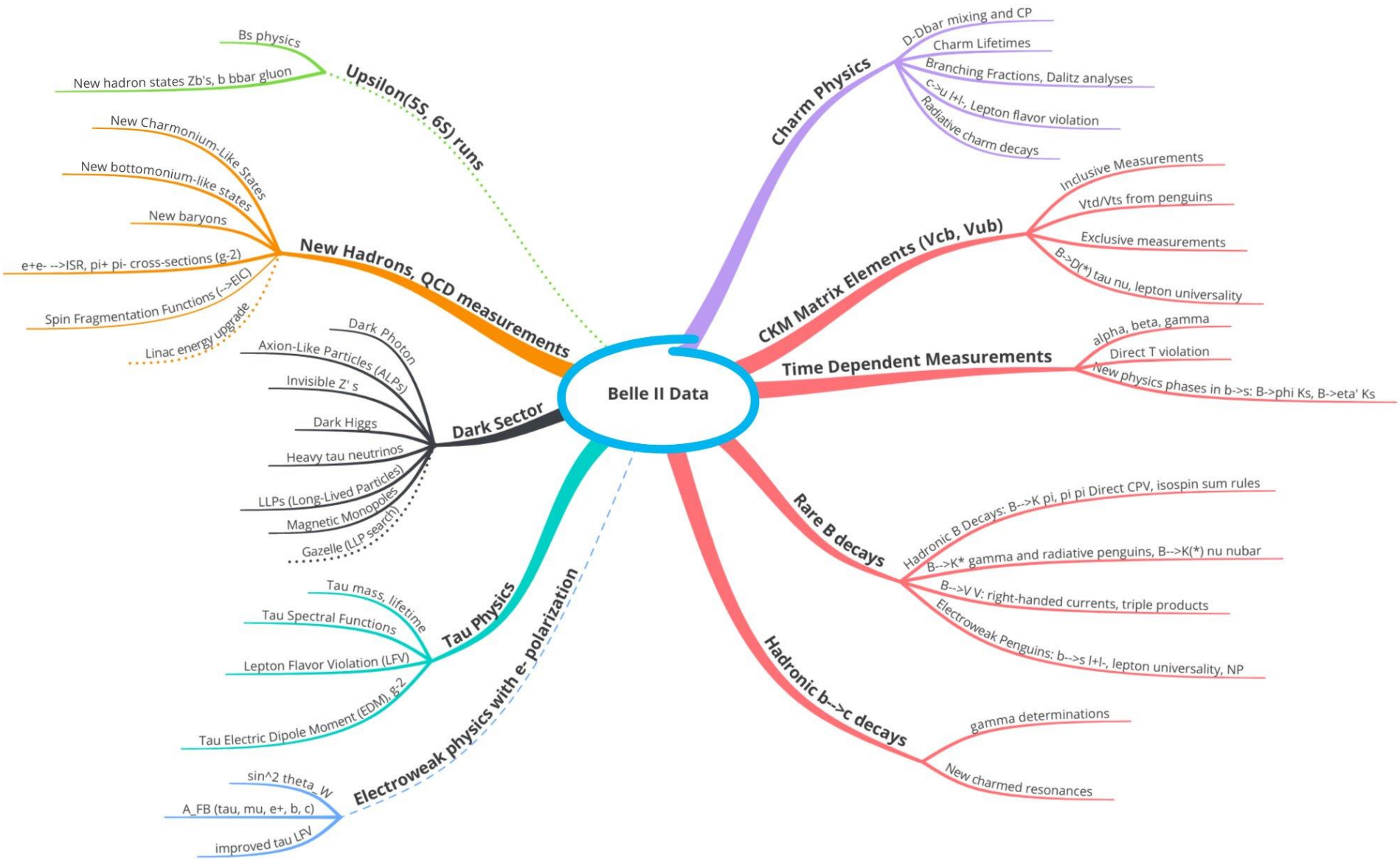
1) Precision test of the standard model (SM): measure the sides and angles of the Unitarity Triangle



2) Indirect searches for signatures of beyond-the-SM physics mostly in loop dominated decays

➨ See the talk by Chandiprasad Kar

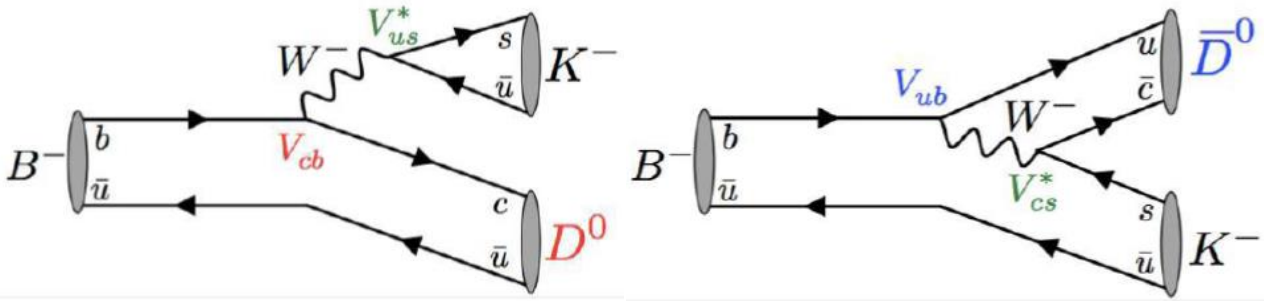
They do much more



➡ LHCb has access to all types of heavy hadrons: B^0, B^+, B_s^0, B_c^+, Λ_b ...

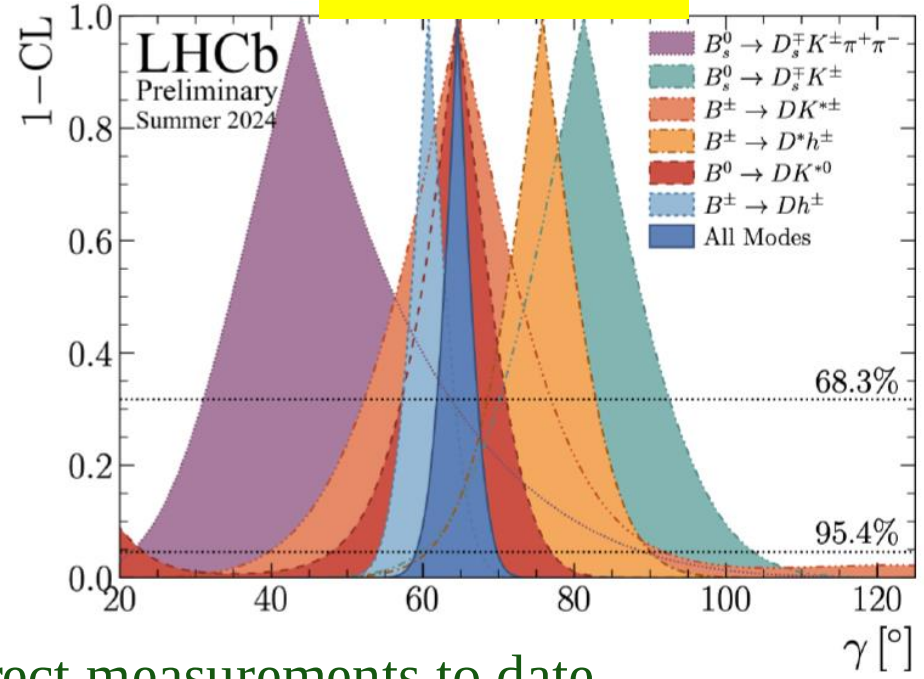
Checking an SM candle: ϕ_3/γ

- Exploit the interference between $b \to c\bar{u}s$ and $b \to u\bar{c}s$ transitions



- Combination of
  - 19 B decay results
  - 11 D decay results
  - 4 new and few updated results
  - 198 input observables to determine 53 parameters

LHCb-CONF-2024-004



$$\gamma = (64.6 \pm 2.8)^\circ$$

➡ Most precise determination from direct measurements to date

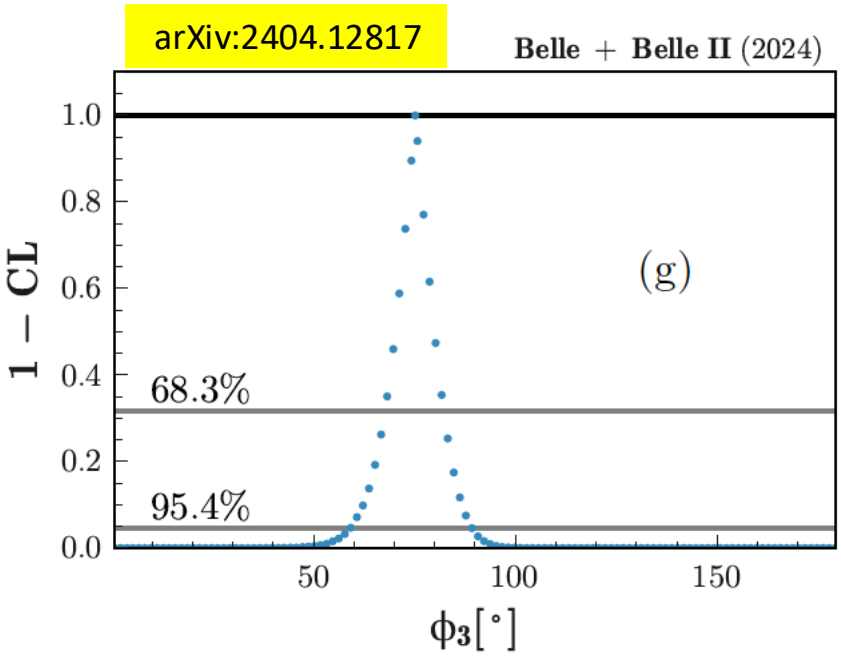
Checking an SM candle: ϕ_3/γ

- Combine measurements based on data (771 fb^{-1}) from Belle with those based on data (up to 362 fb^{-1}) from Belle II

B decay	D decay	Method	Data set (Belle + Belle II)[fb^{-1}]	Ref.
$B^+ \to Dh^+$	$D \to K^0_S\pi^0, K^-K^+$	GLW	711 + 189	[23]
$B^+ \to Dh^+$	$D \to K^+\pi^-, K^+\pi^-\pi^0$	ADS	711 + 0	[15, 24]
$B^+ \to Dh^+$	$D \to K^0_S K^-\pi^+$	GLS	711 + 362	[25]
$B^+ \to Dh^+$	$D \to K^0_S h^-h^+$	BPGGSZ (m.i.)	711 + 128	[26]
$B^+ \to Dh^+$	$D \to K^0_S\pi^-\pi^+\pi^0$	BPGGSZ (m.i.)	711 + 0	[27]
$B^+ \to D^*K^+$	$D^* \to D\pi^0, D \to K^0_S\pi^0, K^0_S\phi, K^0_S\omega, K^-K^+, \pi^-\pi^+$	GLW	210+0	[12]
$B^+ \to D^*K^+$	$D^* \to D\pi^0, D\gamma, D \to K^0_S\pi^-\pi^+$	BPGGSZ (m.d.)	605 + 0	[28]

$$\phi_3 = (75.2 \pm 7.6)^\circ$$

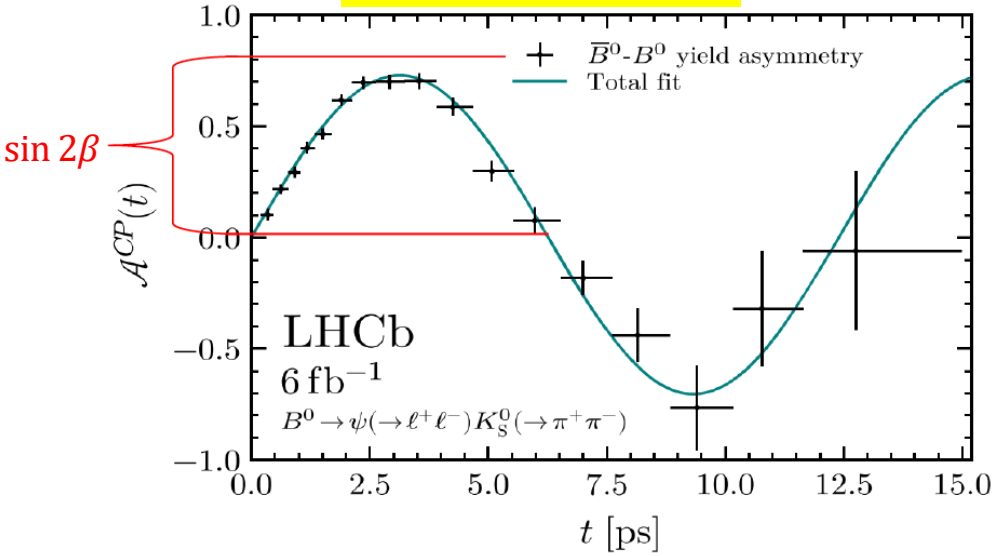
arXiv:2404.12817

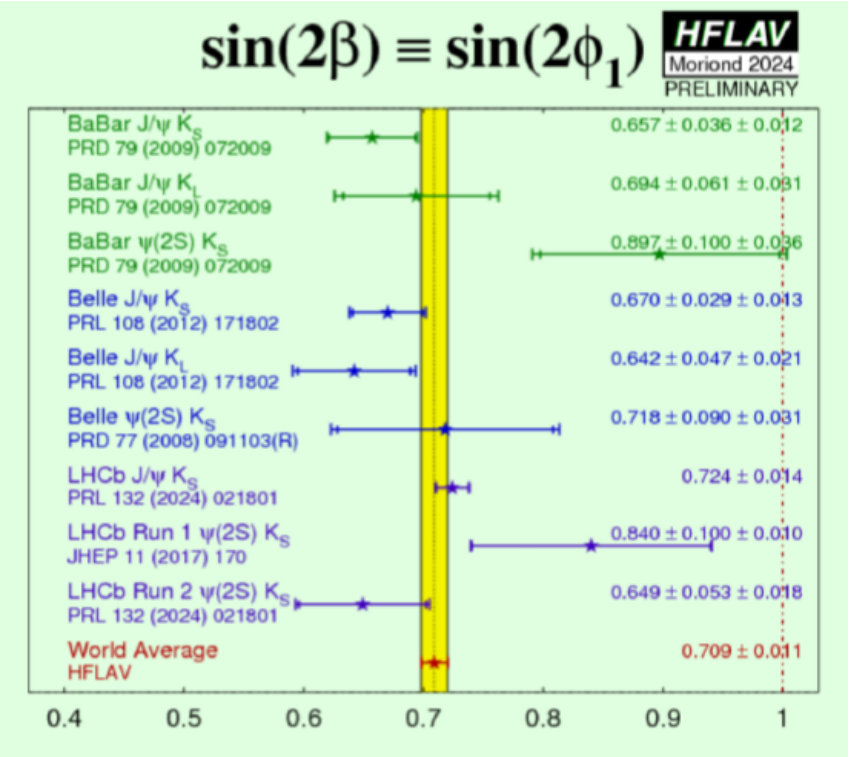


Improved determination of sin 2β

- Flagship measurements from first-generation e^+e^- flavor factories (Belle and BABAR) that confirmed the Kobayashi-Maskawa mechanism for CP violation

PRL 132 (2024) 021801



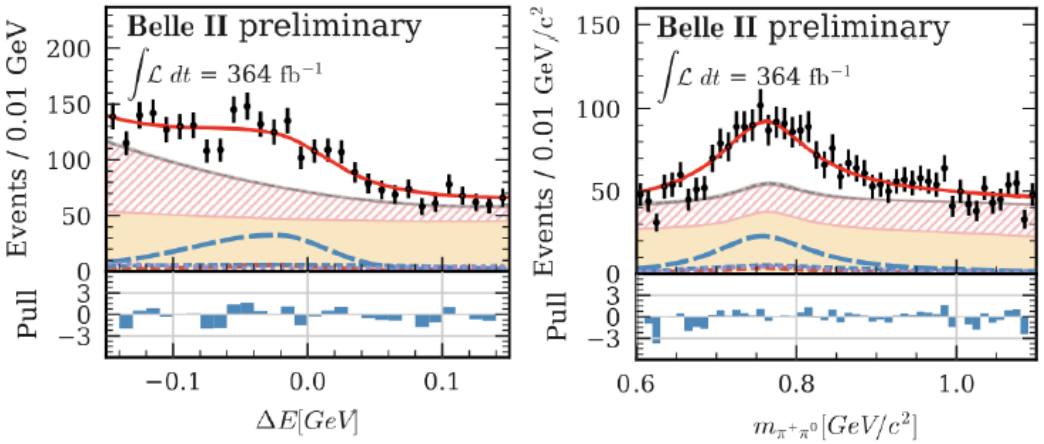


$$\sin 2\beta = 0.717 \pm 0.013(\text{stat}) \pm 0.008(\text{syst})$$

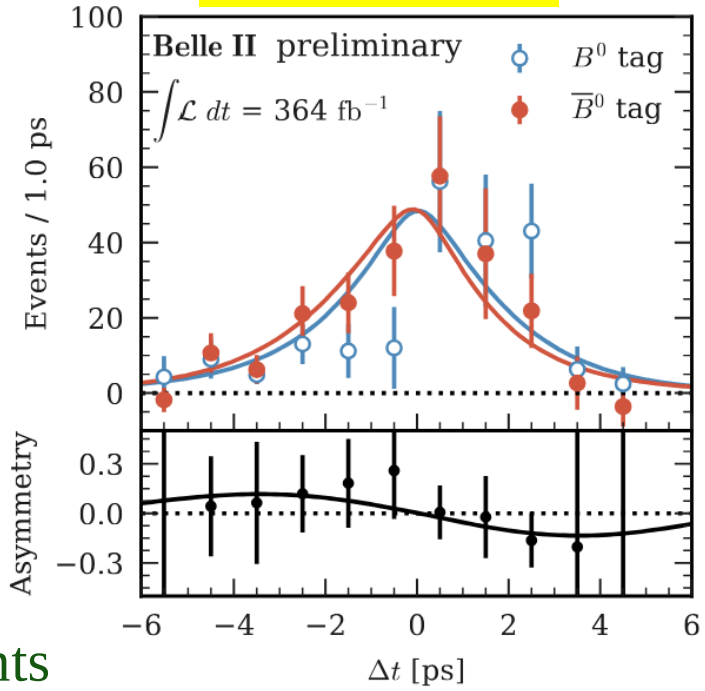
➡ Most precise single measurement of sin 2β to date

What about the 3rd angle?

- Challenging measurement of $B^0 \to \rho^+\rho^-$
  - P → VV decay (requires angular analysis)
  - Two soft neutral pions from ρ mesons
  - Large continuum background



Paper in preparation



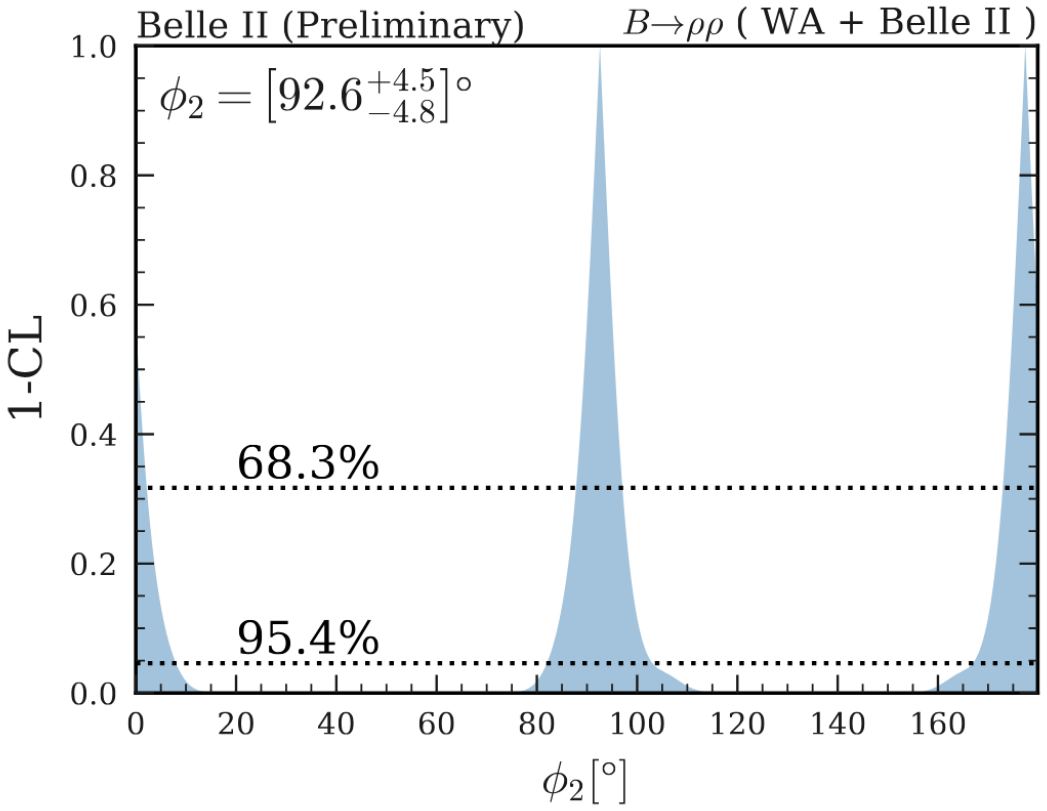
- In agreement with previous e^+e^- experiments (measurement will be difficult for LHCb)

Experiment	S	C	$N_{B\bar{B}}$
Belle II	$-0.26 \pm 0.19 \pm 0.08$	$-0.02 \pm 0.12^{+0.06}_{-0.05}$	388×10^6
Belle	$-0.13 \pm 0.15 \pm 0.05$	$0.00 \pm 0.10 \pm 0.06$	772×10^6
BABAR	$-0.17 \pm 0.20^{+0.05}_{-0.06}$	$0.01 \pm 0.15 \pm 0.06$	384×10^6

What about the 3rd angle?

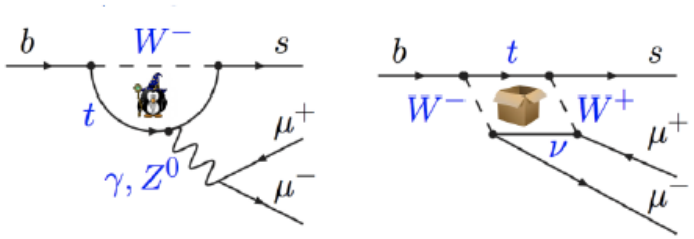
- Inclusion of the Belle II $B^0 \to \rho^+\rho^-$ results results in 6% improvement in world average

$$\phi_2 = \left(92.6^{+4.5}_{-4.8}\right)^\circ$$



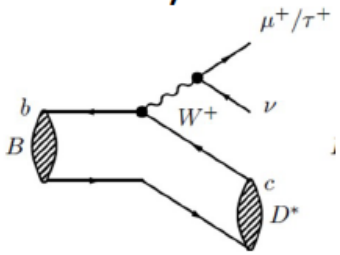
Anomalies of two types

- $b \to sll$ – flavour-changing neutral current – **loop only in SM**

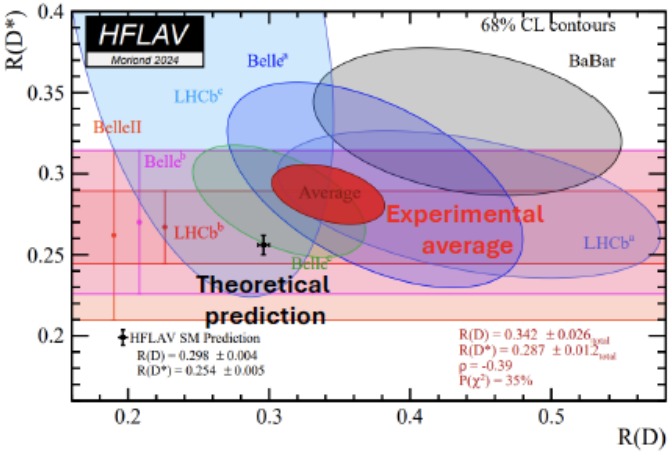


- 2-3 standard deviation tensions in angular distributions and absolute branching fractions
  - but long-distance contributions must be considered, which weaken these tensions
  - LHCb arXiv:2405.17347
- Lepton-universality violation in ratios cancelled Christmas 2022
  - LHCb PRD 108, 032002

- $b \to c\tau\nu$ - measured relative to light lepton decay in exclusive decays



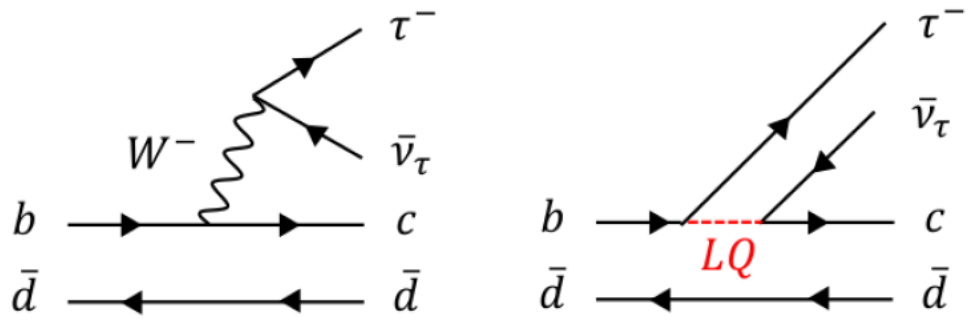
Longstanding ~3 standard deviation tension



R(D*): subject of great interest

- Measure the lepton flavor universality ratio

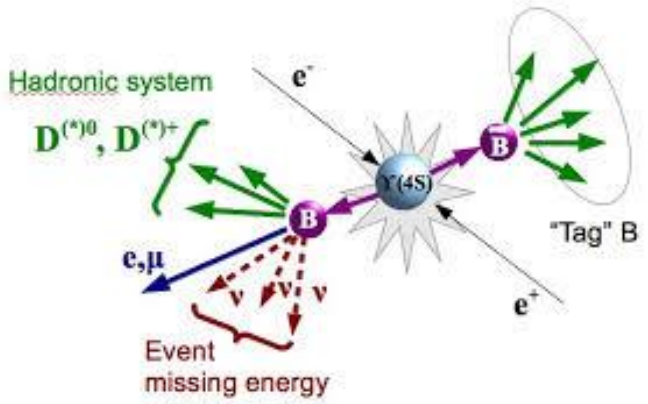
$$R(D^*) = \frac{\mathcal{B}(B \to D^* \tau \nu)}{\mathcal{B}(B \to D^* \ell \nu)}$$



- Sensitive to BSM contribution, e.g., leptoquark
- First Belle II result (189 fb^{-1}) based on the hadronic B tagging method

arXiv:2401.02840

$$R(D^*) = 0.262\ ^{+0.041}_{-0.039}(\text{stat})\ ^{+0.035}_{-0.032}(\text{syst})$$



- Control sample statistics is the main source of systematic uncertainty

➡ Comparable statistical precision as Belle with only ¼ the data

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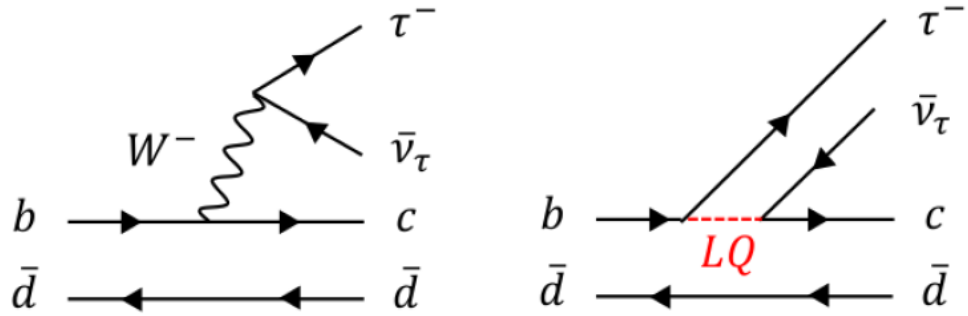

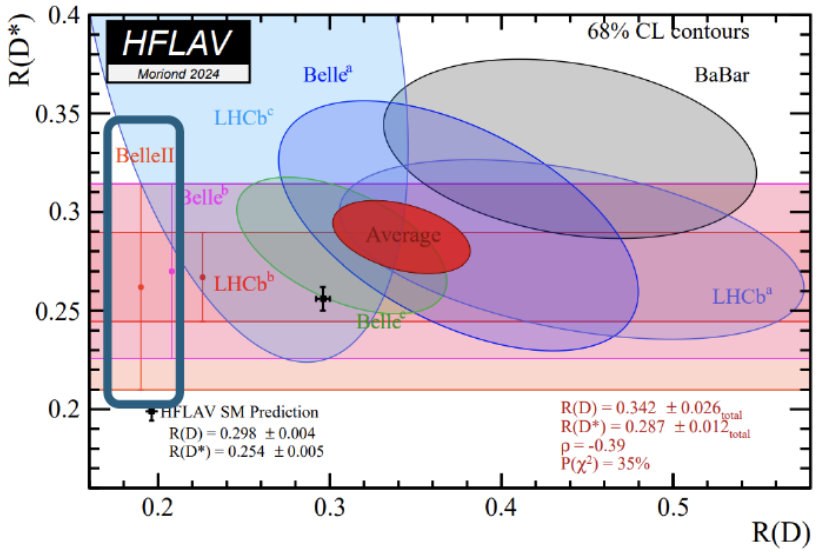

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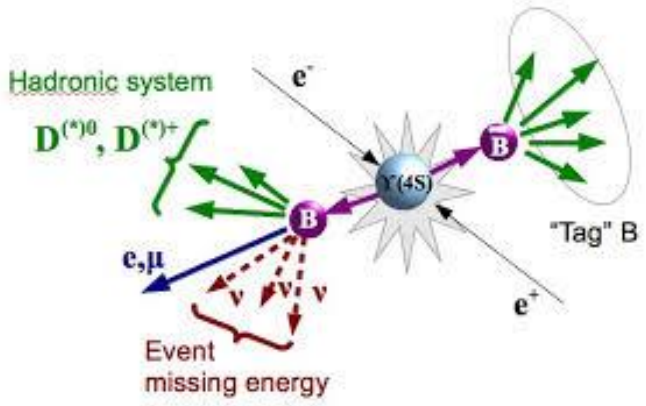

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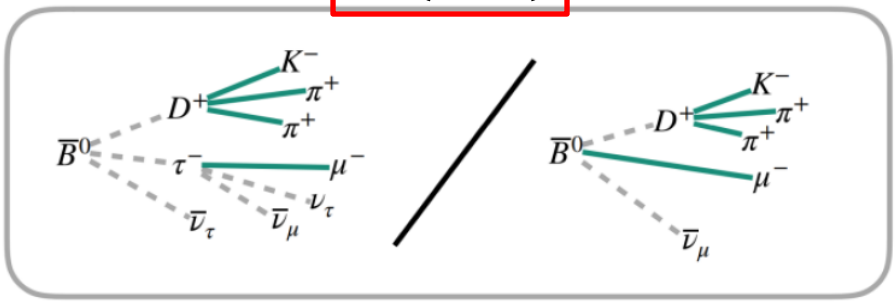
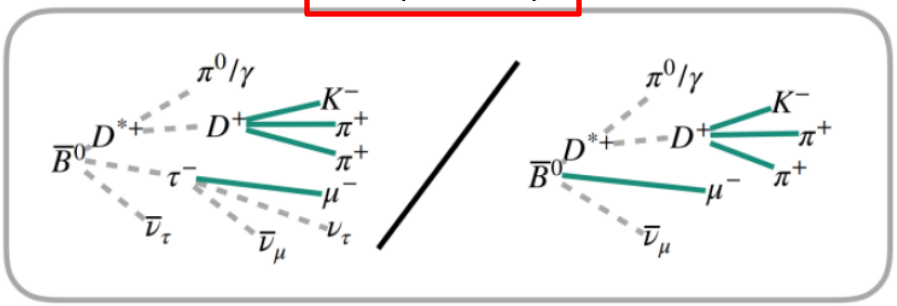
What does LHCb say?

$R(D^+)$



$R(D^{*+})$

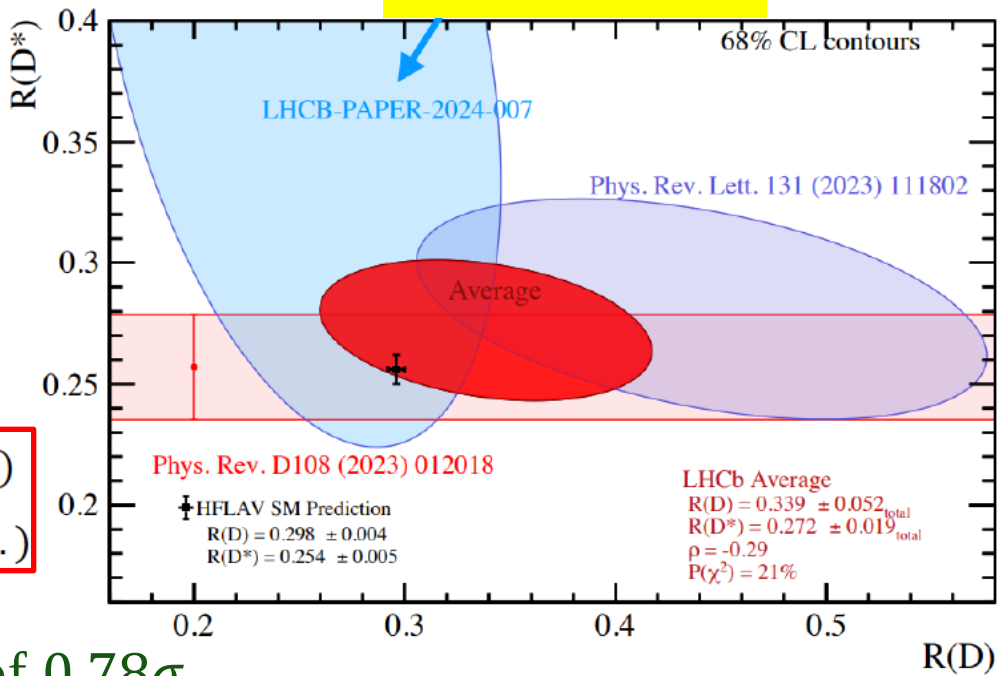


- At one point, I was bit unsure if LHCb could really do this measurement involving multiple neutrinos...
- Feed-down from $D^{*+} \to D^+\pi^0$, $D^+\gamma$ with π^0/γ not reconstructed gives access to $R(D^{*+})$ in the same final state

$$R(D^+) = 0.249 \pm 0.043\,(\text{stat.}) \pm 0.047\,(\text{syst.})$$

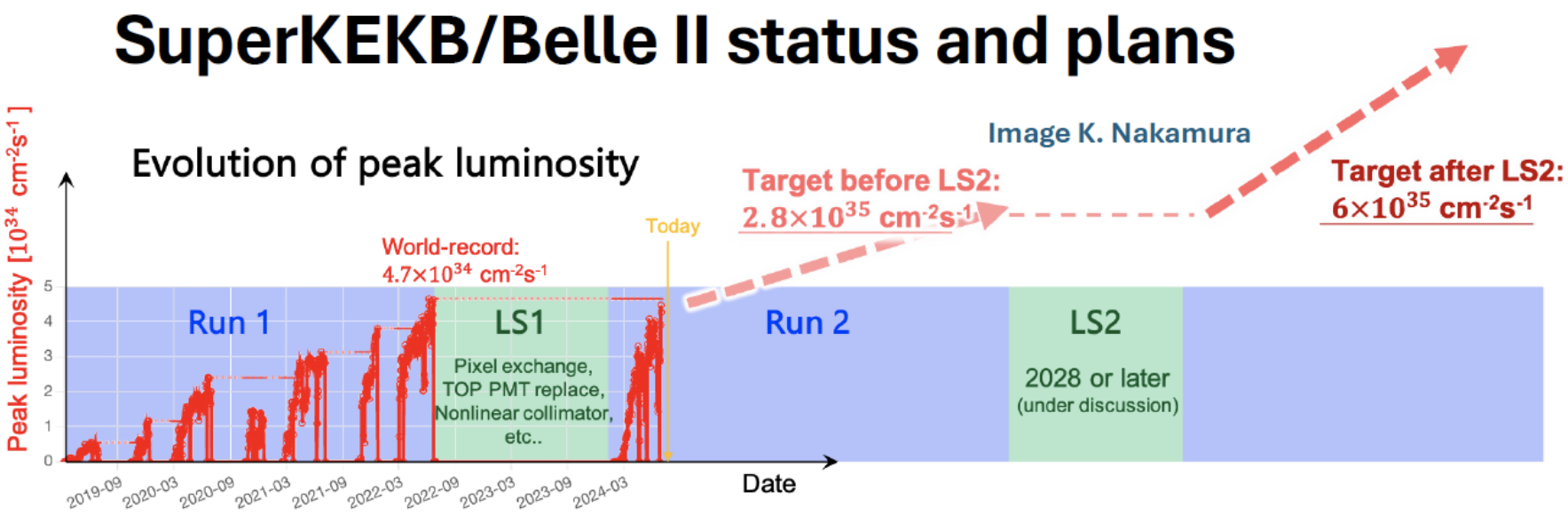
$$R(D^{*+}) = 0.402 \pm 0.081\,(\text{stat.}) \pm 0.085\,(\text{syst.})$$

LHCB-PAPER-2024-007



➡ Compatible with SM at the level of 0.78σ

What's future plan for Belle II?



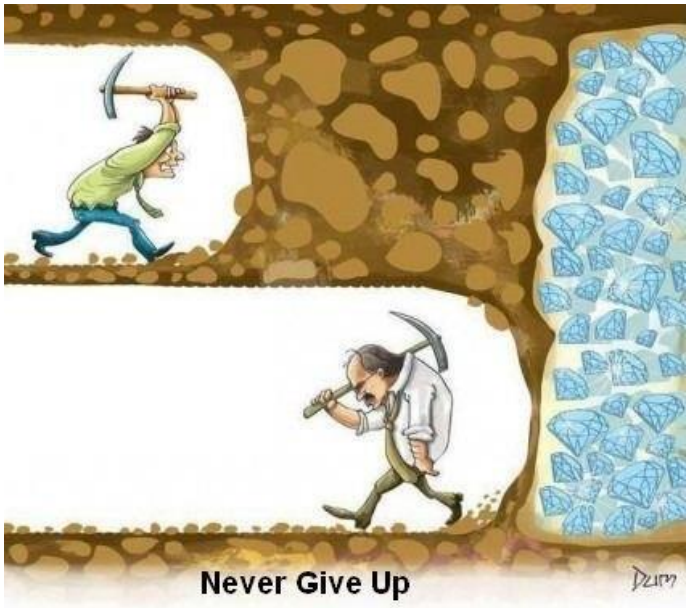
- Run 2 is expected to be long (may be end 2028 or later)
  - Steady integration at a peak luminosity of $\sim 2 \times 10^{35} \mathrm{cm}^{-2}\mathrm{s}^{-1}$ for several ab^{-1} data
  - After Run 2, go for upgrade to reach the design luminosity and accumulate tens of ab^{-1}

➡ LHCb upgrade plan by...

Summary

- Focus on some of the recent analyses from Belle II and LHCb related to the Unitarity Triangle and LFU test
- Number of interesting studies that I have been unable to cover in this talk can be accessed from the Belle II and LHCb publication pages
- Much more to come from these flavor frontier experiments

➢ Stay tuned …



Additional information

More to be added