Highlights of Recent LHCb Results

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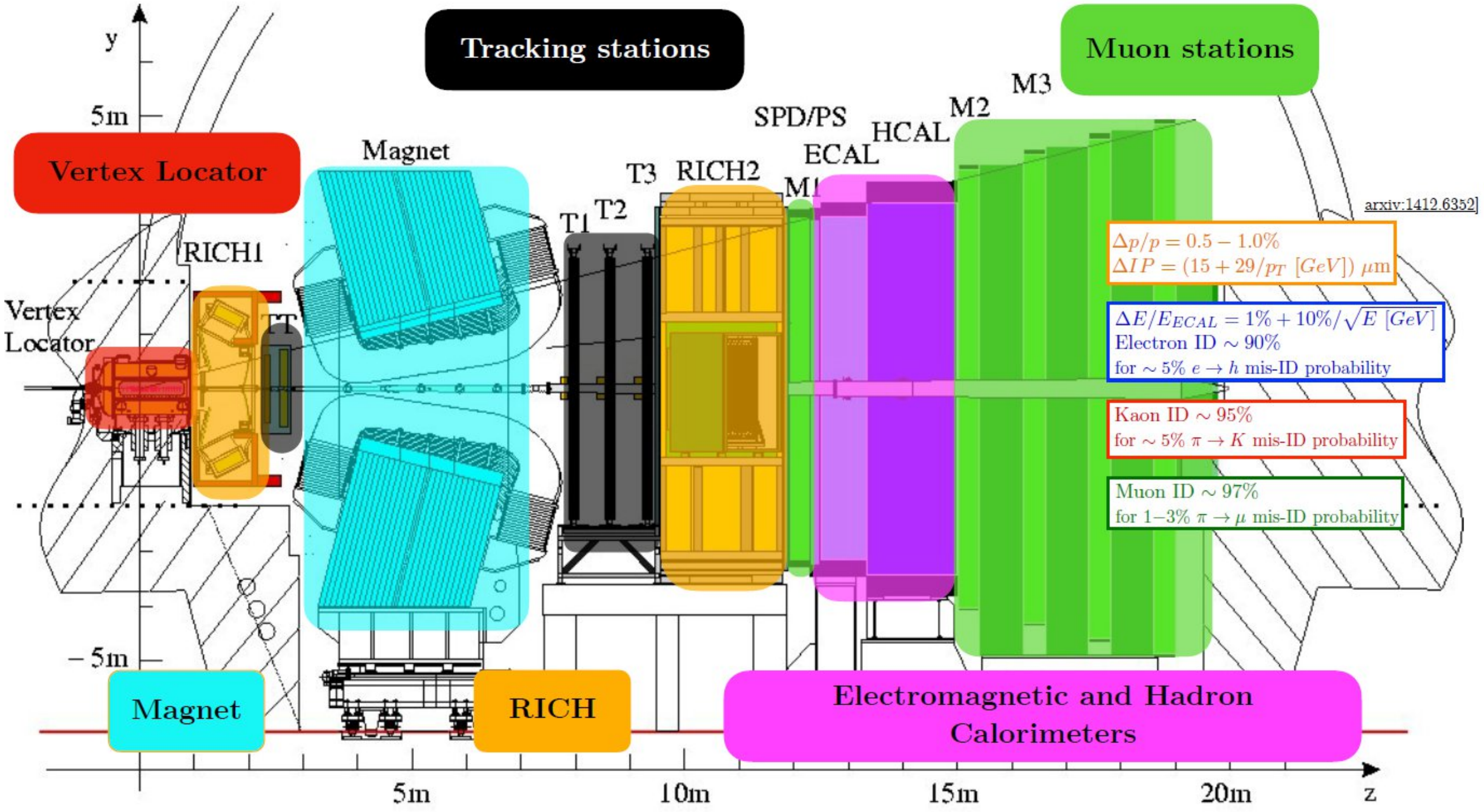
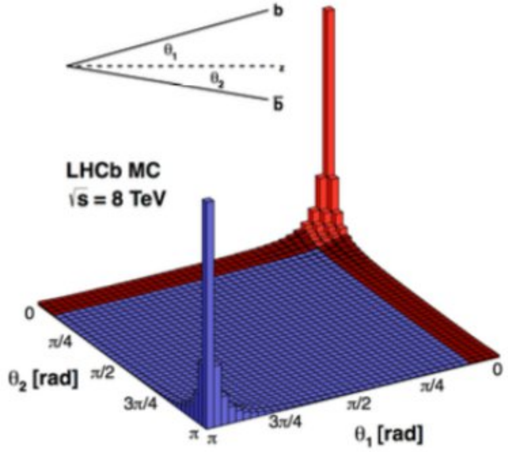
HFCPV 2025, Beijing

Outline

- LHCb experiment in Runs 1-2,3
- Highlights of recent HF&CPV results on
  - Beauty sector:
    - CPV — See 尹航's CPV talk on Monday
    - LFU & Rare decays — See 王纪科's semileptonic talk on Monday
  - Charm sector:
    - Mixing & CPV
    - Rare decays
- A complete list here — See 张黎明's Hadron Spec talk on Sunday
- Summary & outlook

LHCb in Runs 1-2 (2011-2018)

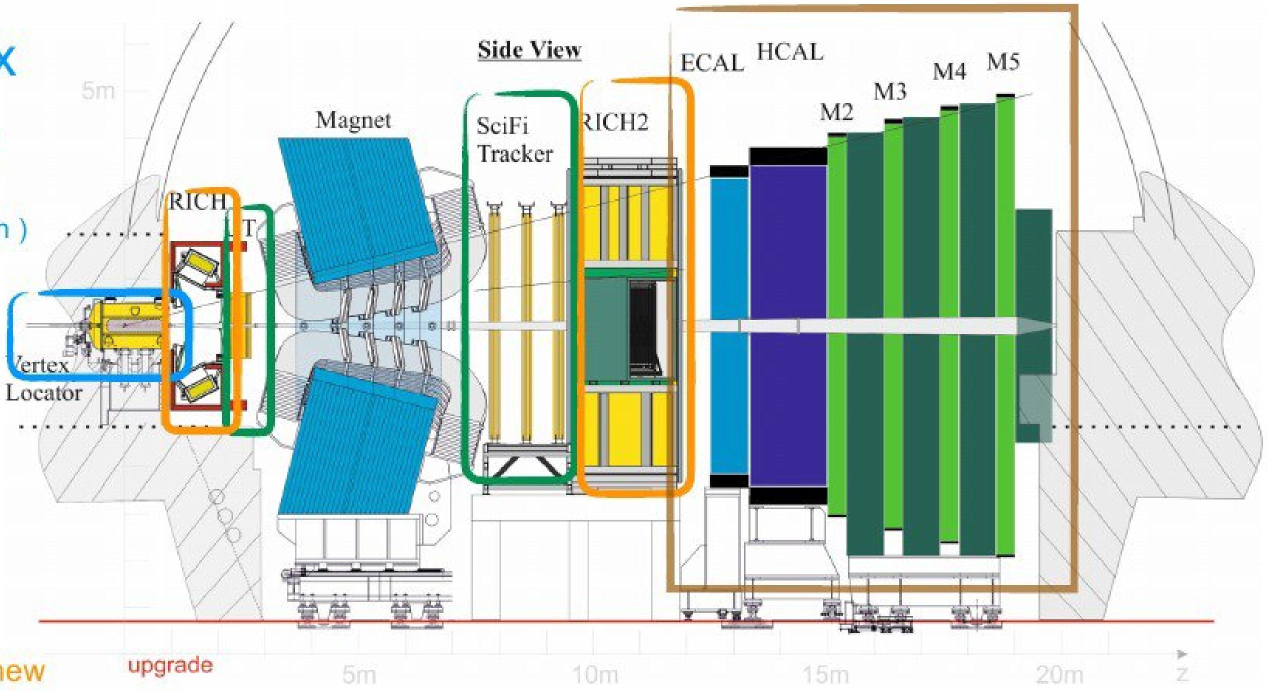




LHCb is designed and optimized for HF & CPV

LHCb in Run3 (2022-)

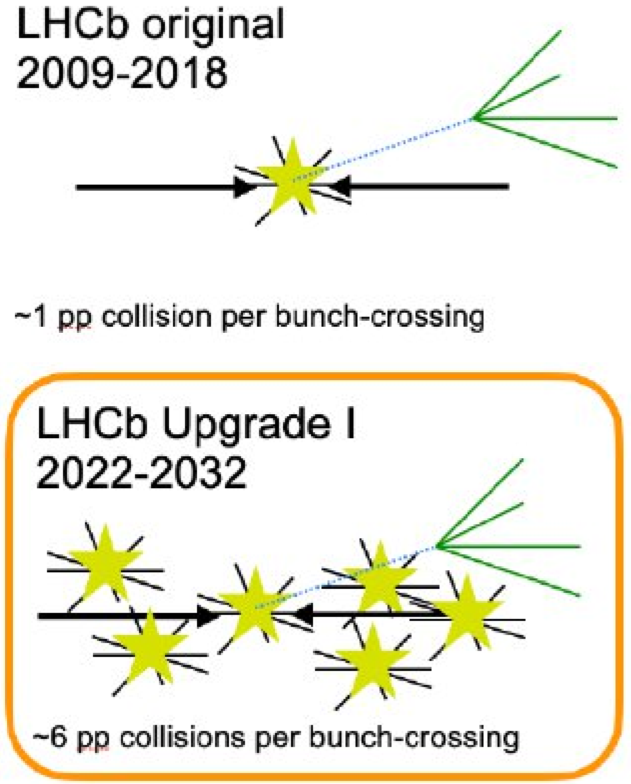
New Vertex detector (Si-microstrip-> Si-pixel, closer to beam, improved IP resolution)



New PID detector, new photon detectors, readout + modified optics/mechanics

New tracking system (Si-strip + straw-tubes ->Scintillating fibres,+ Si-strip UT > granularity)

New read out

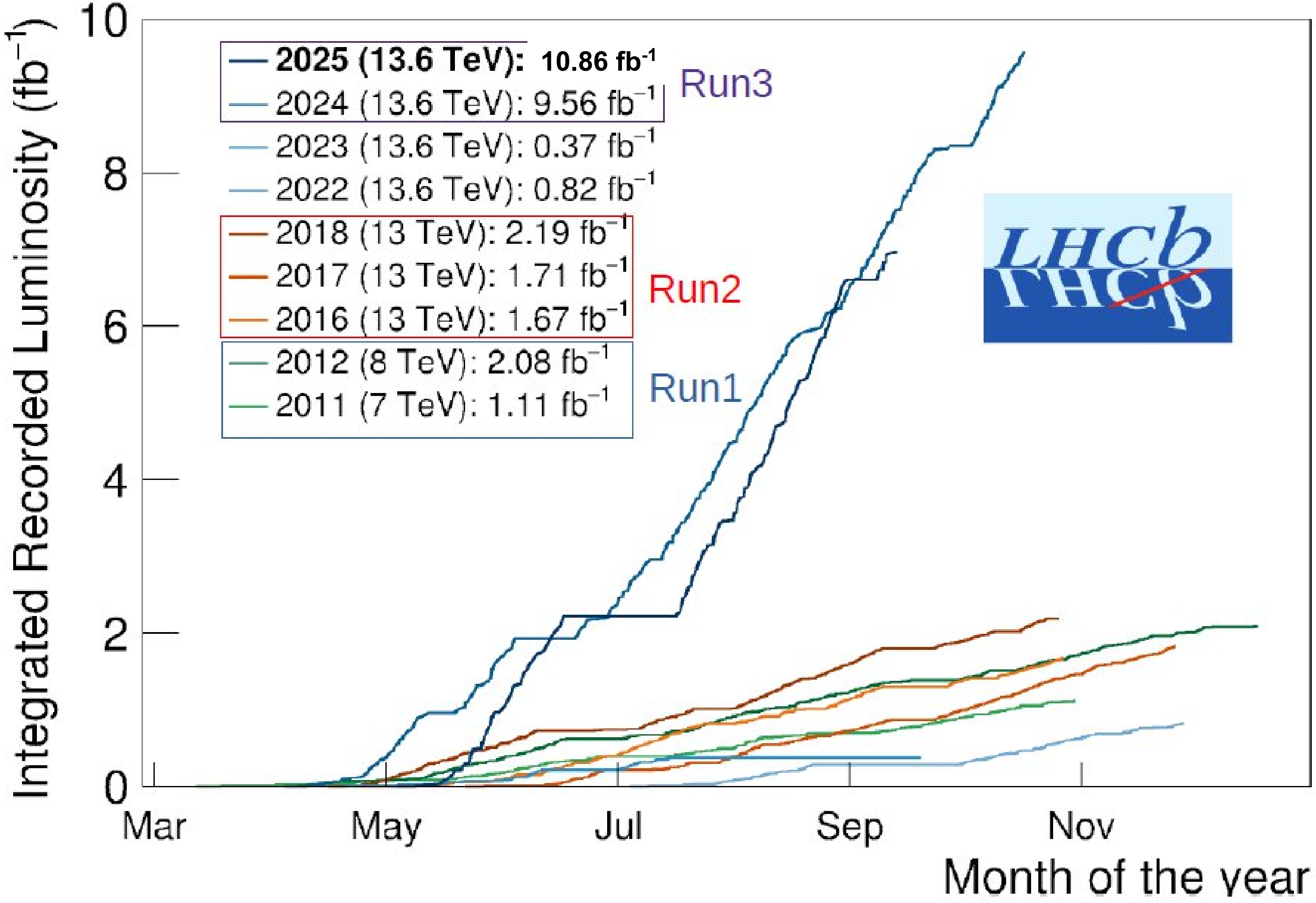


Running with 5x higher instantaneous luminosity!

+ new DAQ/data centre

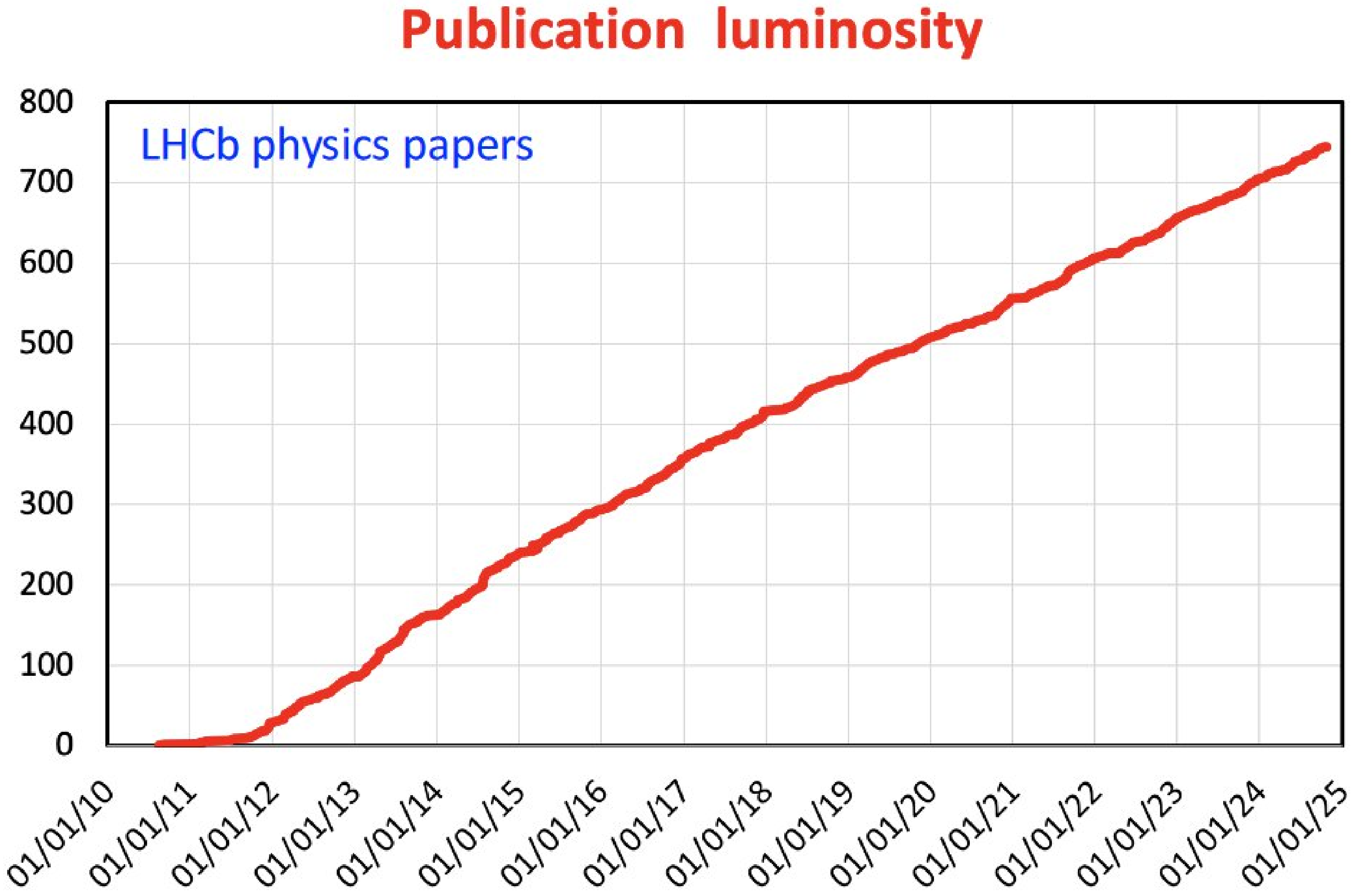
Excellent detector performance since 2024!

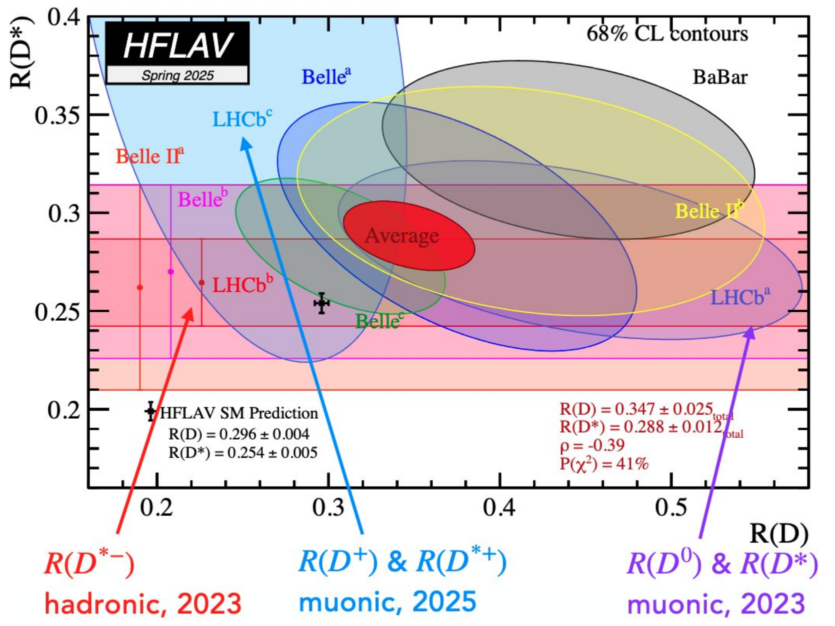
LHCb datasets

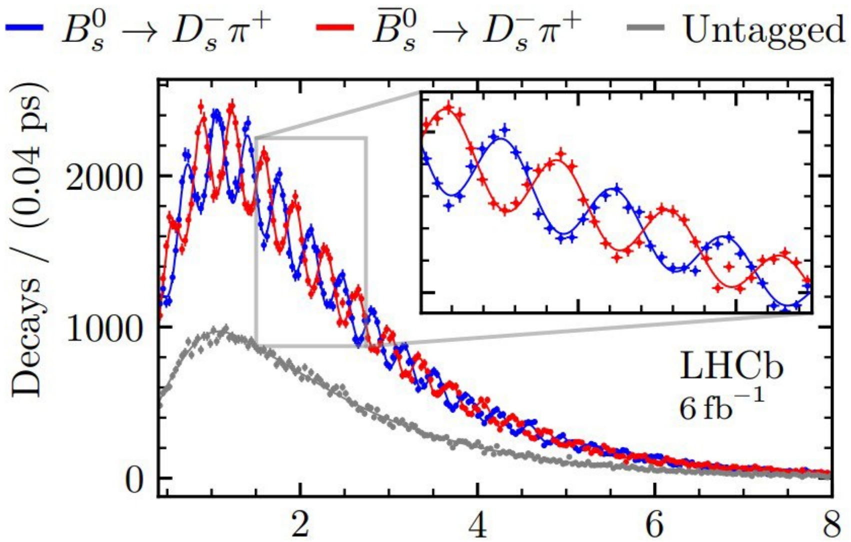


Most of results shown today are based on Runs 1-2 datasets

LHCb physics program

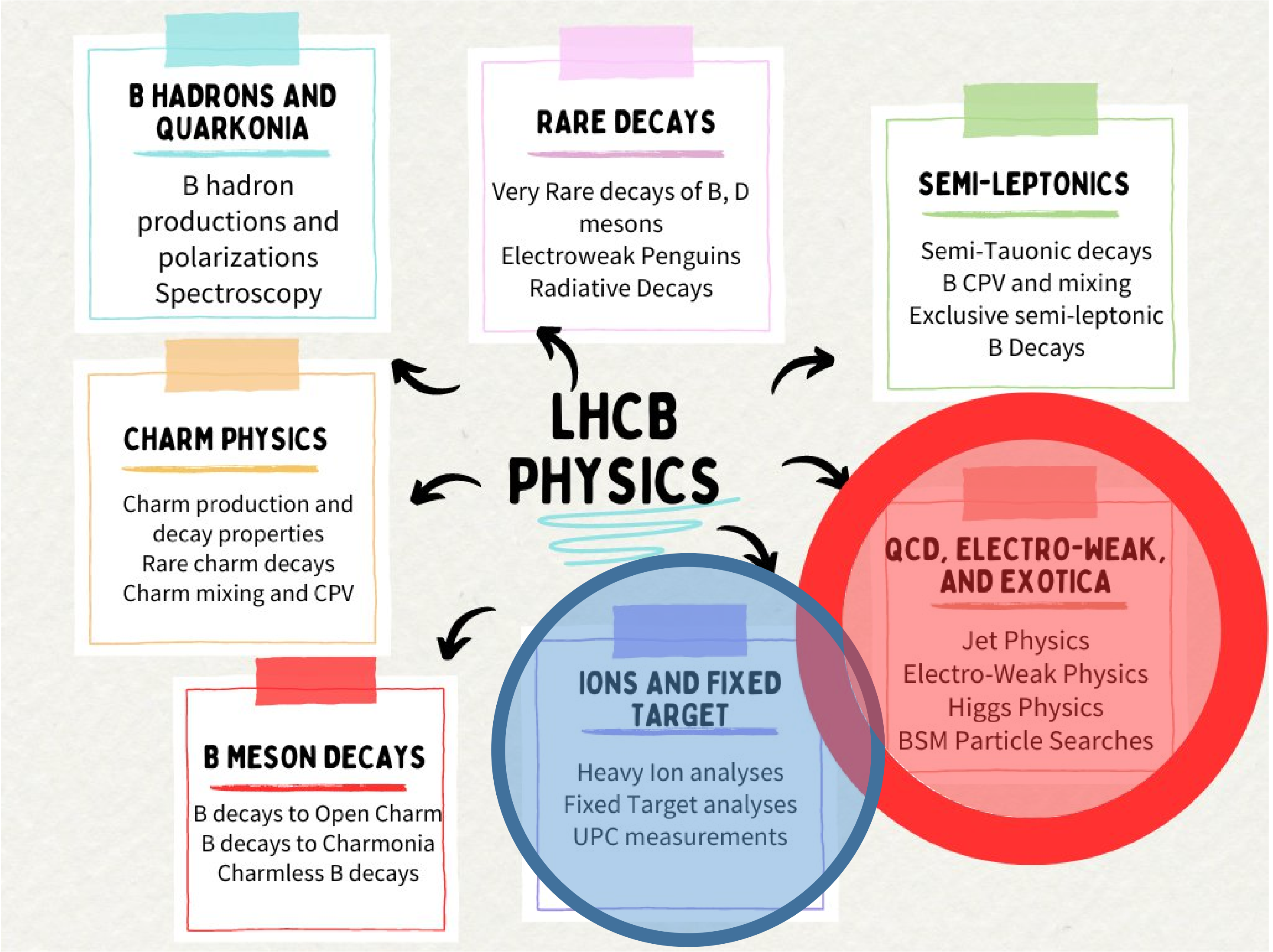


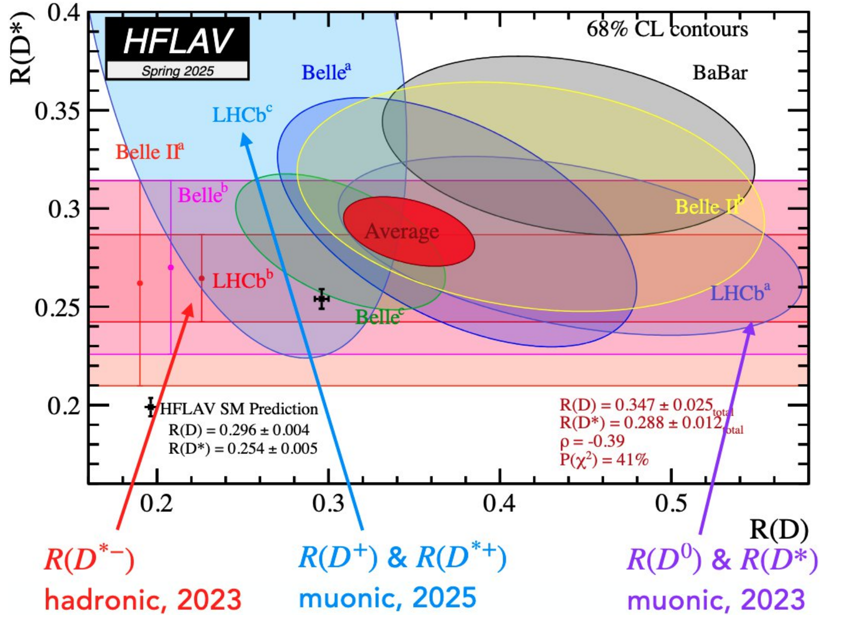


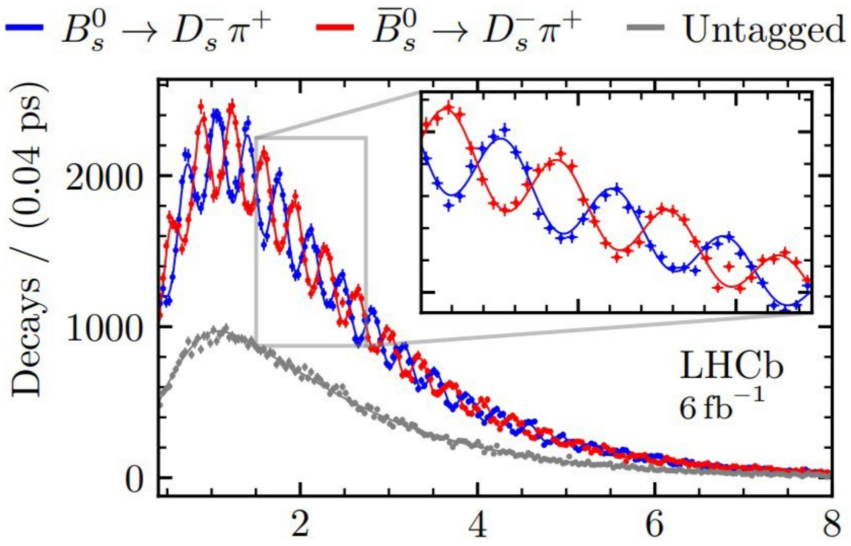


Nat. Phys. 18, 1–5 (2022)

LHCb physics program







Nat. Phys. 18, 1–5 (2022)

CP violation in baryon decay: the observation

1956
Parity violation
T. D. Lee,
C. N. Yang,
C. S. Wu *et al.*

1963
Cabibbo Mixing
N. Cabibbo

1964
Strange mesons:
***CP* violation in K^0**
decays
J. W. Cronin,
V. L. Fitch *et al.*

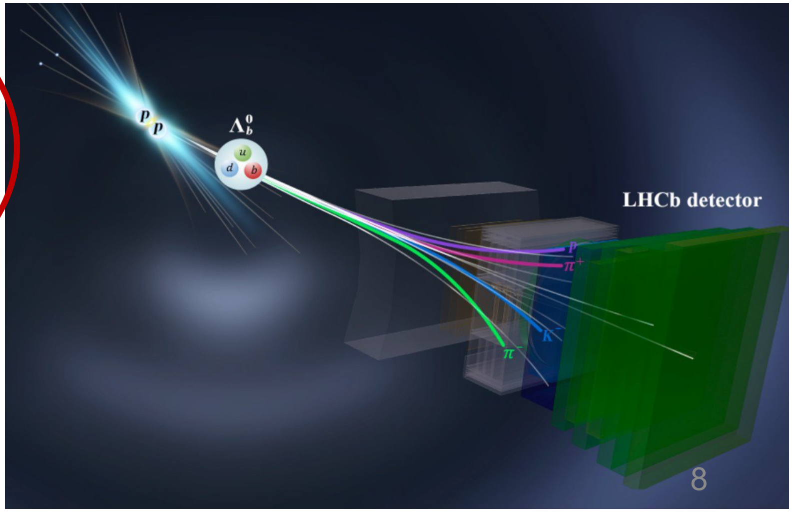
1973
The CKM matrix
M. Kobayashi,
T. Maskawa

2001
Beauty mesons:
***CP* violation in B^0**
decays
BaBar and Belle
collaborations

2019
Charm mesons:
***CP* violation in D^0**
decays
LHCb collaboration

TODAY

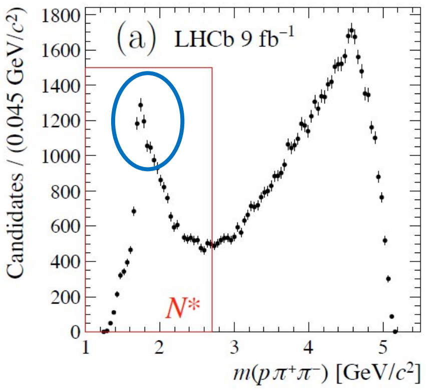
2025
Beauty baryons:
***CP* violation in Λ_b^0**
decays
LHCb collaboration



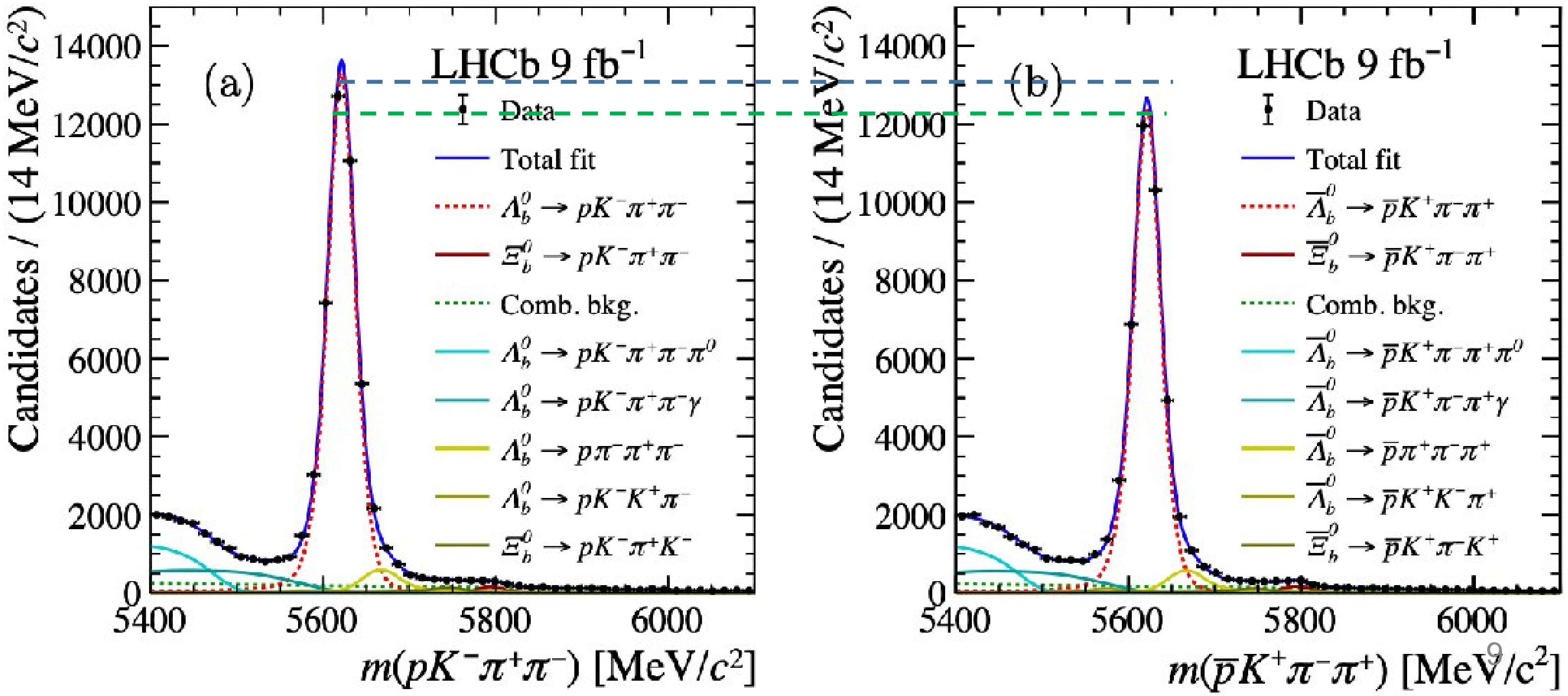
Nature 643 (2025) 1223

CPV in $\Lambda_b^0 \to pK^-\pi^+\pi^-$ decay

- Using Runs 1-2 dataset (9 fb^{-1})
- Corrections for production & detection asymmetries as measured in $\Lambda_b^0 \to \Lambda_c^+(\to pK^-\pi^+)\pi^-$ control channel
- Phase-space integrated $A_{CP} = (2.45 \pm 0.46 \pm 0.10)\,\%$ (**5.2σ**)
- CP asymmetries also measured in different PHSP regions



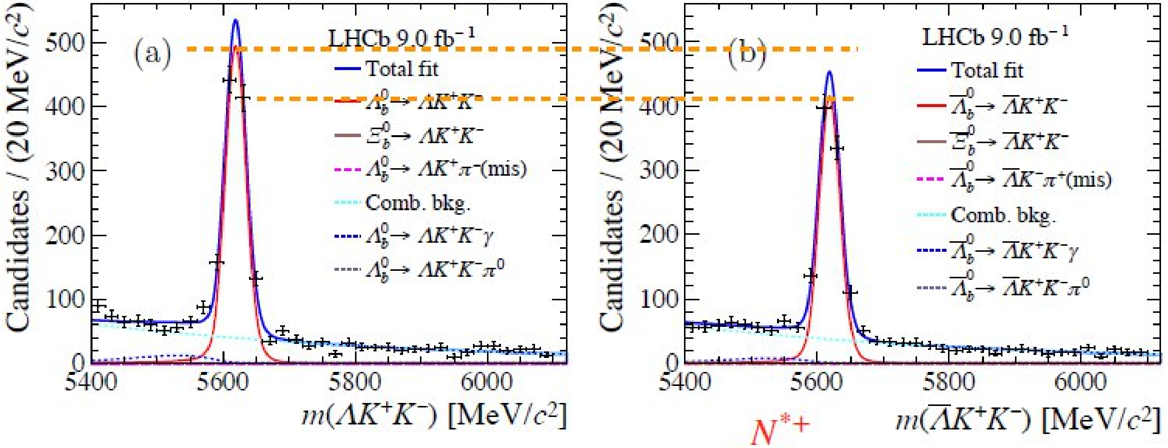
$(5.39 \pm 0.86 \pm 0.10)\%$ (6.0σ)



PRL 134 (2025) 101802

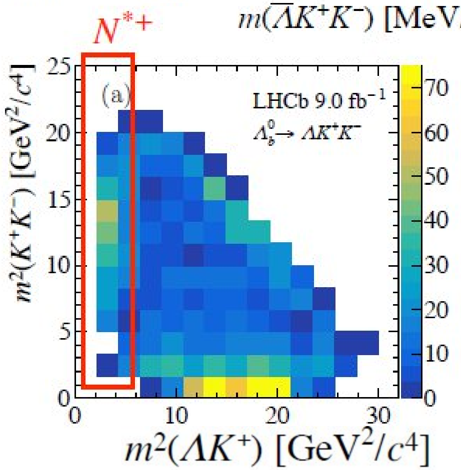
CPV in $\Lambda_b^0 \to \Lambda K^+ K^-$ decay: the evidence

- Using Runs 1-2 dataset (9 fb^{-1})
- Study of Λ_b^0 and Ξ_b^0 decays to $\Lambda h^+ h'^-$
- Asymmetries are measured wrt control channel $\Lambda_b^0 \to \Lambda_c^+ (\to \Lambda \pi^+) \pi^-$
- Evidence at 3.1σ for CPV in $\Lambda_b^0 \to \Lambda K^+ K^-$ decay
- Significance of 3.2σ with phase space constrained to $\Lambda_b^0 \to N^{*+} (\to \Lambda K^+) K^-$



$$\boxed{\Delta\mathcal{A}^{CP} = (8.3 \pm 2.8)\%}$$

Channel	$m(h^+h'^-)$	$m(\Lambda h^+)$	$\Delta\mathcal{A}^{CP}$
$\Lambda_b^0 \to \Lambda\phi\,(\to K^+K^-)$	$< 1.10\,\mathrm{GeV}/c^2$	—	$0.150 \pm 0.055 \pm 0.021$
$\Lambda_b^0 \to N^{*+}(\to \Lambda K^+)K^-$	$> 2.20\,\mathrm{GeV}/c^2$	$< 2.90\,\mathrm{GeV}/c^2$	$0.165 \pm 0.048 \pm 0.017$
$\Lambda_b^0 \to N^{*+}(\to \Lambda K^+)\pi^-$	—	$< 2.30\,\mathrm{GeV}/c^2$	$-0.078 \pm 0.051 \pm 0.027$
$\Lambda_b^0 \to \Lambda f\,(\to \pi^+\pi^-)$	$< 1.70\,\mathrm{GeV}/c^2$	—	$0.088 \pm 0.069 \pm 0.021$



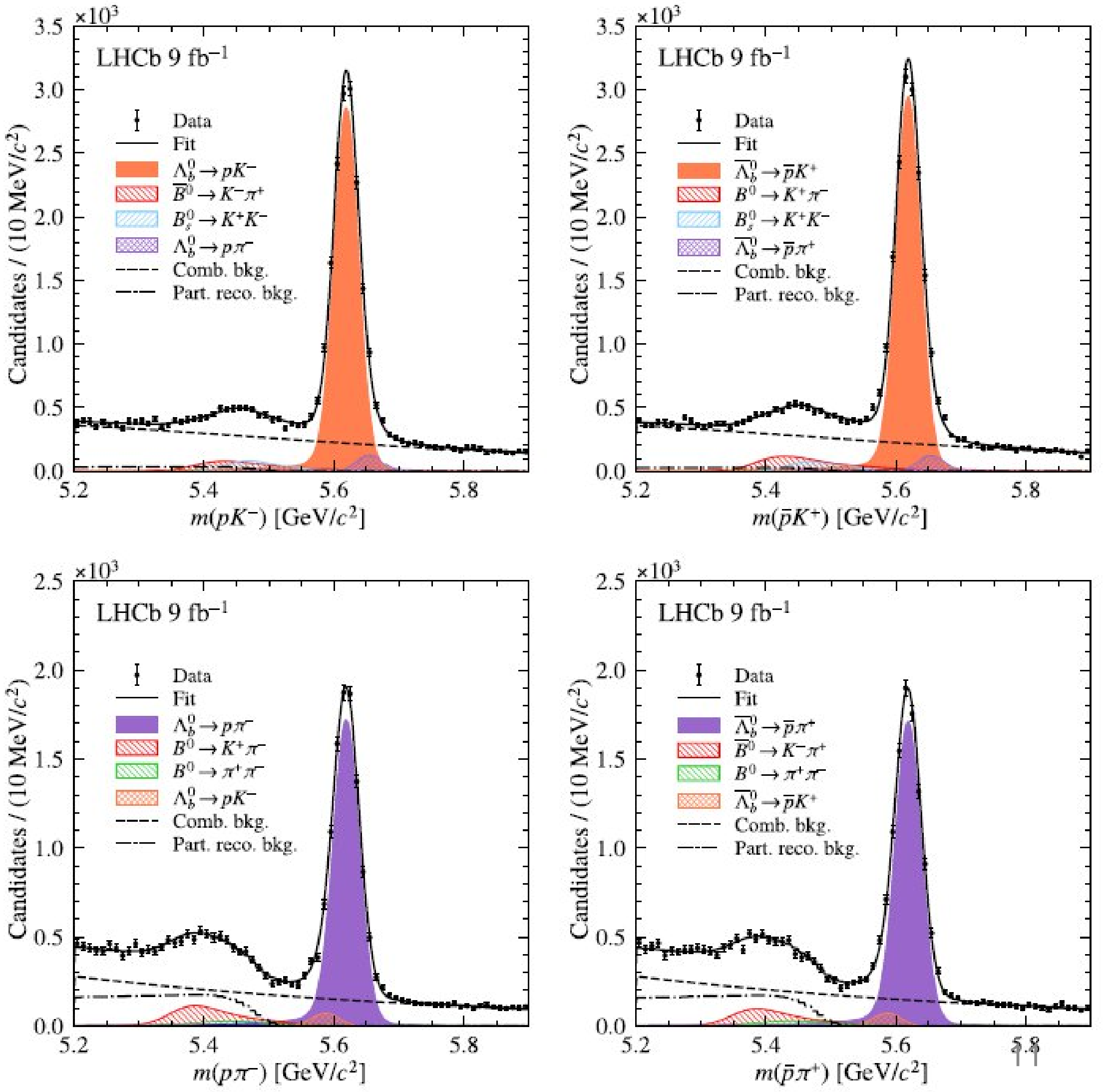
PRD 111 (2025) 092004

CPV in $\Lambda_b^0 \to ph^-$ decays

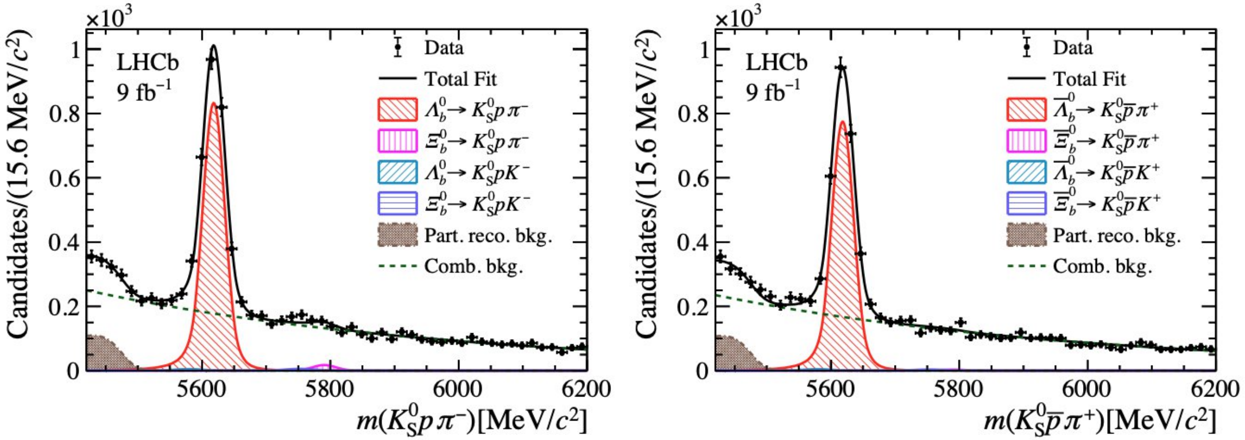
- Using Runs 1-2 dataset (9 fb^{-1})
- Obtained asymmetries:

$$A_{CP}^{pK^-} = (-1.1 \pm 0.7 \pm 0.4)\%,$$
$$A_{CP}^{p\pi^-} = (0.2 \pm 0.8 \pm 0.4)\%,$$

No CPV found
Most precise to date



CPV in $\Lambda_b^0\left(\Xi_b^0\right) \to pK_S^0 h^-$



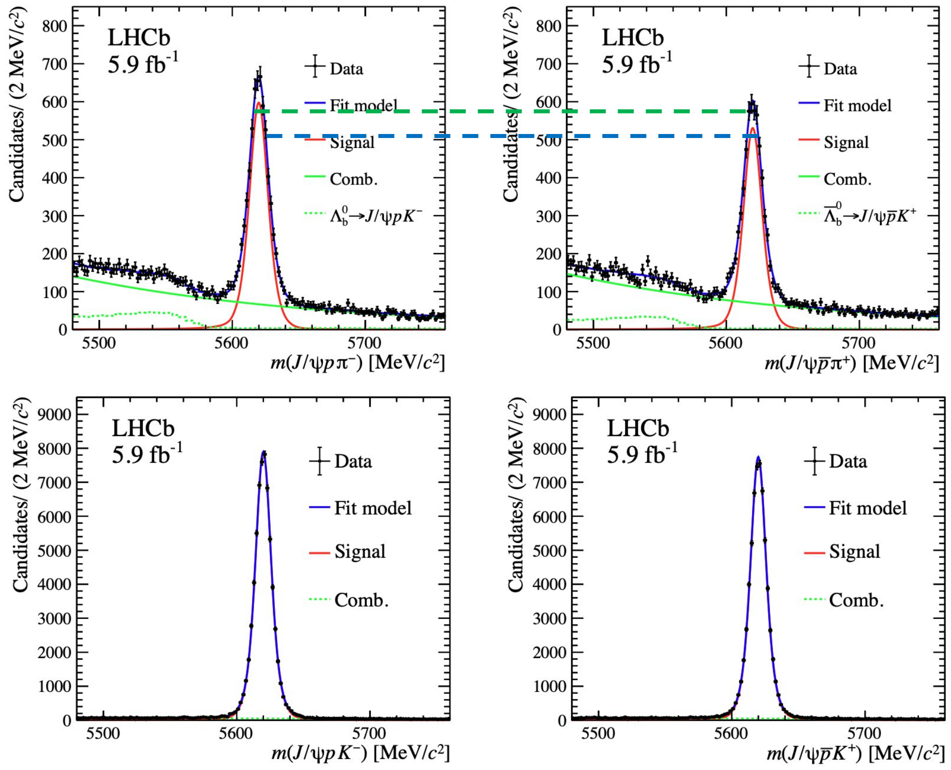
$$A_{CP}\left(\Lambda_b^0 \to pK_s^0\pi^-\right) = (3.4 \pm 1.9_{stat} \pm 0.9_{syst})\%$$

$$A_{CP}\left(\Lambda_b^0 \to pK_s^0K^-\right) = (\ 2 \pm 13_{stat} \pm 5_{syst})\%$$

$$A_{CP}\left(\Xi_b^0 \to pK_s^0K^-\right) = (22 \pm 15_{stat} \pm 10_{syst})\%$$

First observation of $\Lambda_b^0\left(\Xi_b^0\right) \to pK_S^0K^-$ decays

CPV in $\Lambda_b^0 \to J/\psi p h^-$



$$\Delta A_{CP}^{\text{Run }1+2} = (4.31 \pm 1.06 \pm 0.28)\%$$

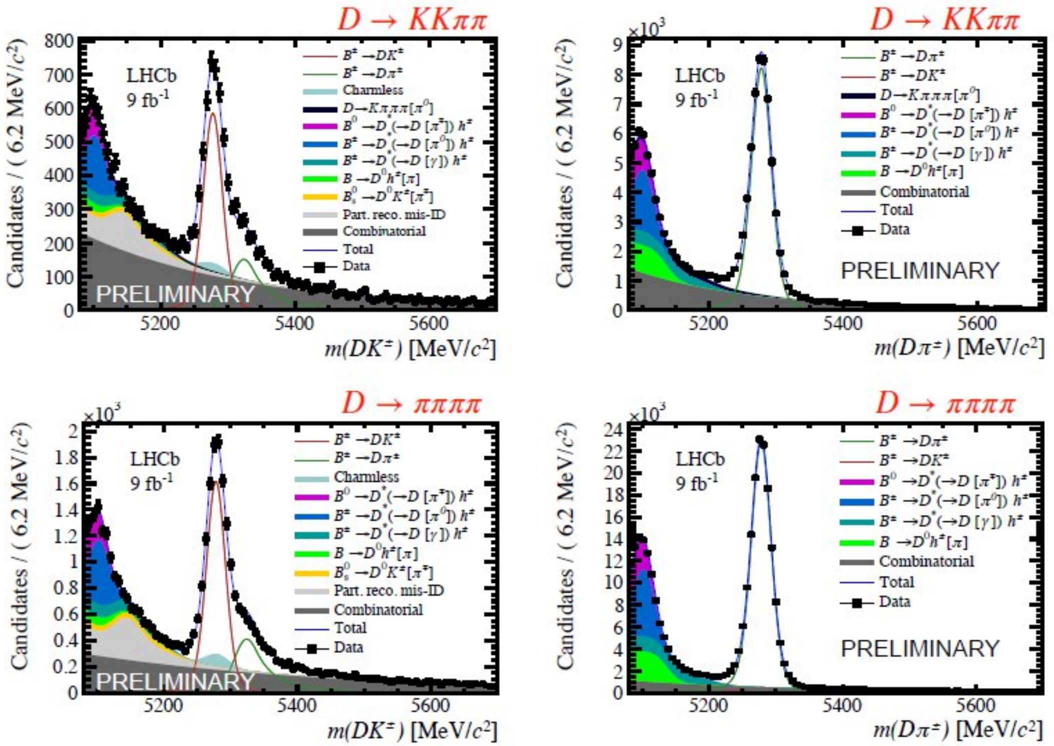
First evidence (3.9σ) of CPV in baryon decays to charmonia

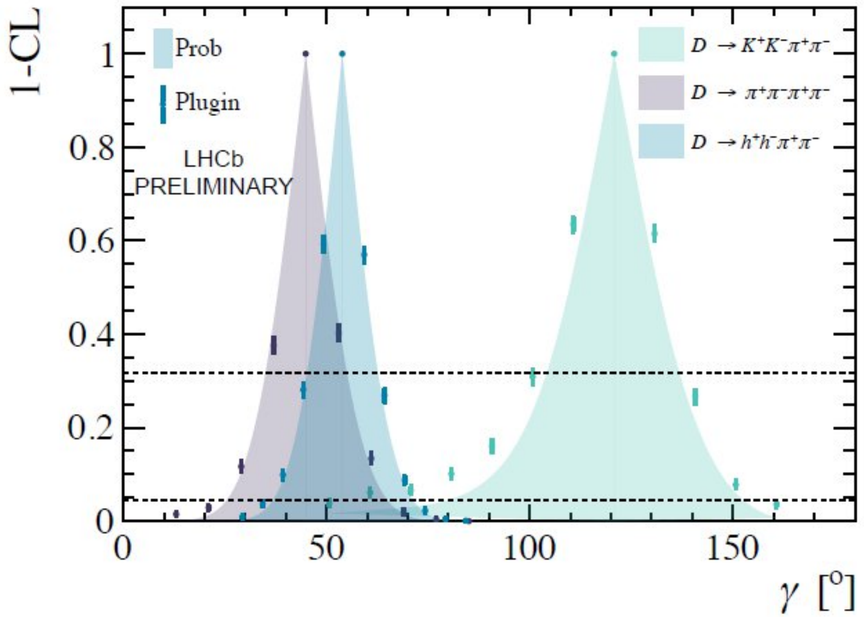
CKM angle γ with $B^{\pm} \to [h^+h^-\pi^+\pi^-]_D h^{\pm}$

- Model-independent measurement of CKM angle γ in $B^{\pm} \to [K^+K^-\pi^+\pi^-]_D\, h^{\pm}$ and $B^{\pm} \to [\pi^+\pi^-\pi^+\pi^-]_D\, h^{\pm}$, with $D = D^0$ or $\bar{D}^0$
- Use BESIII measurement of strong phase in phase-space bins of the $D^0/\bar{D}^0$ decays

BESIII, PRD 112 (2025) 012015

- Analysis based on $9\ \mathrm{fb}^{-1}$ from Run1+2





$$\gamma = (53.9^{+9.5}_{-8.9})^{\circ}$$

PRL 134 (2025) 101801

CPV in $B^+ \to J/\psi\pi^+$: first evidence

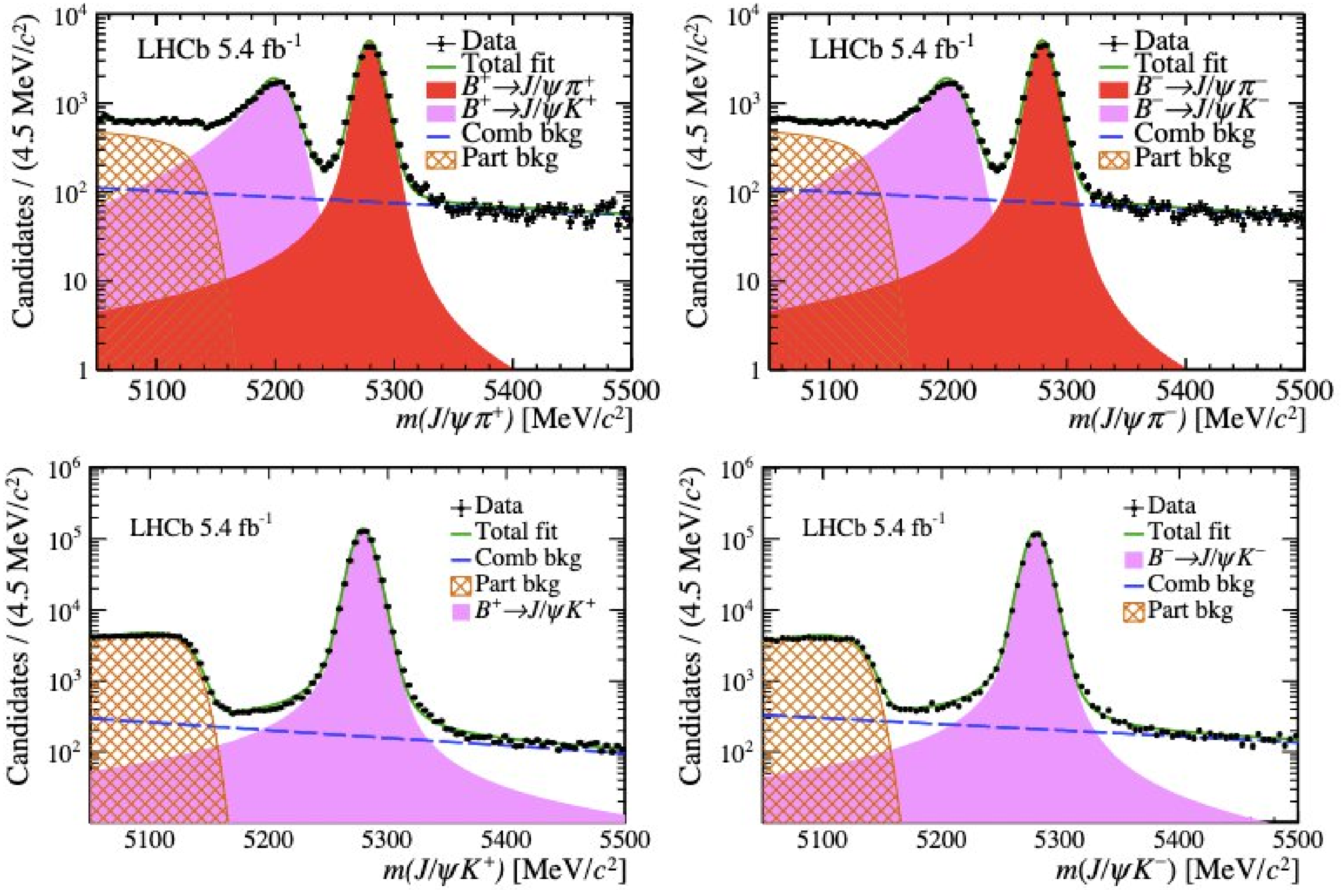
- Using Run 2 dataset
- CP asymmetry measured wrt the control channel $B^+ \to J/\psi K^+$:

$$\Delta\mathcal{A}^{CP} \equiv \mathcal{A}^{CP}(B^+ \to J/\psi\pi^+) - \mathcal{A}^{CP}(B^+ \to J/\psi K^+).$$

- Combined Runs1-2 9fb^{-1} result:

$$\Delta\mathcal{A}^{CP} = (1.42 \pm 0.43 \pm 0.08) \times 10^{-2}$$

First evidence (3.2σ) of DCPV in beauty decays to charmonia



arXiv:2508.13563

Polarization & CPV in $B^+ \to \rho^0 K^{*+}$

$$f_L = \frac{|A_0|^2}{|A_0|^2 + |A_\perp|^2 + |A_\parallel|^2}$$

- Charmless $B \to VV$ decays: three independent helicity states
- 5D amplitude analysis of $B^+ \to (\pi^+\pi^-)(K_S^0\pi^+)$ in the phase-space region: $(0.3 < m(\pi^+\pi^-) < 1.1)\ \mathrm{GeV}/c^2$, $(0.75 < m(K_S^0\pi^+) < 1.2)\ \mathrm{GeV}/c^2$

- *CP*-averaged f_L, $f_L^{\mathrm{avg}} = 0.721 \pm 0.027\,(\mathrm{stat}) \pm 0.030\,(\mathrm{syst})$
  - Consistent with BaBar and most theory predictions, but more precise

- Direct *CP* asymmetry

$$\mathcal{A}_{CP} = \frac{\sum_\lambda (|\bar{A}_\lambda|^2 - |A_\lambda|^2)}{\sum_\lambda (|\bar{A}_\lambda|^2 + |A_\lambda|^2)},$$

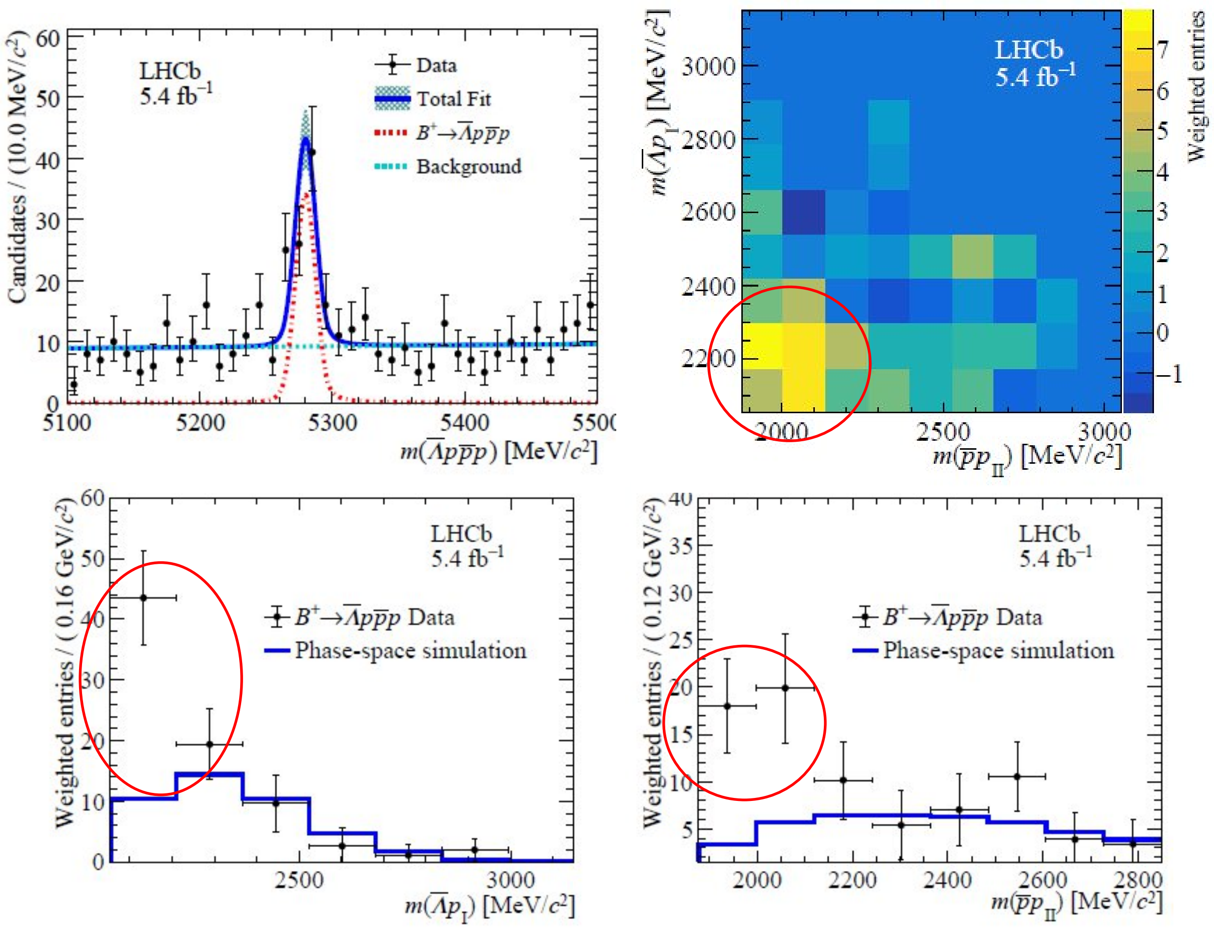
where $\lambda \in \{0, \perp, \parallel\}$

- Measured to be $\mathcal{A}_{CP} = 0.507 \pm 0.062\,(\mathrm{stat}) \pm 0.017\,(\mathrm{syst})$
  - First observation of *CP*-violation in this decay mode at 9σ!

First observation & CPV in $B^+ \to \bar{\Lambda}p\bar{p}p$

- Dominated by $b \to s$ transition, sensitive to NP
- Using Run2 5.4 fb^{-1} data
- First observation with BF measured:
  - $\mathcal{B}\left(B^+ \to \bar{\Lambda}p\bar{p}p\right) = (2.15 \pm 0.35 \pm 0.12 \pm 0.28) \times 10^{-7}$
- Direct CP asymmetry measured:

$$\mathcal{A}_{CP} = (5.4 \pm 15.6 \pm 2.4)\%$$

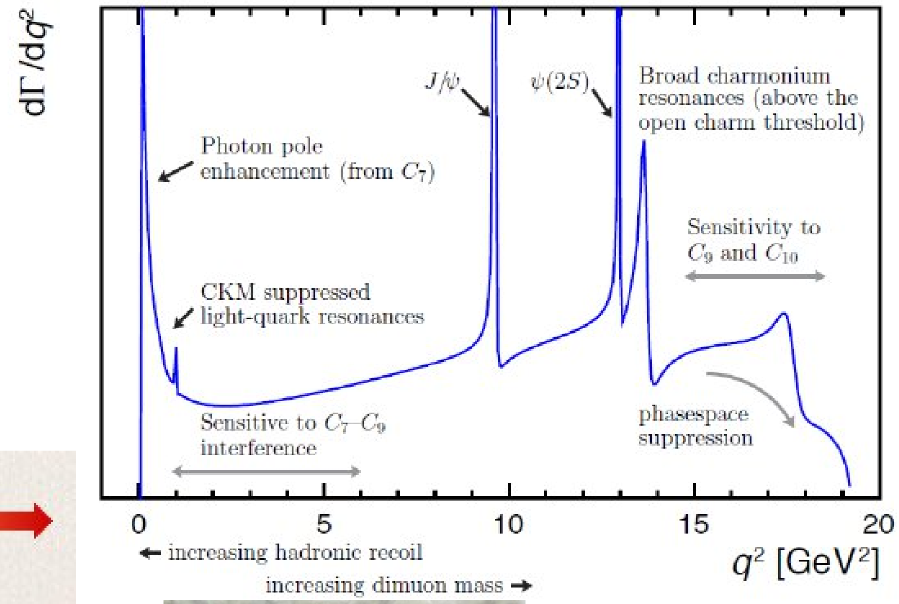


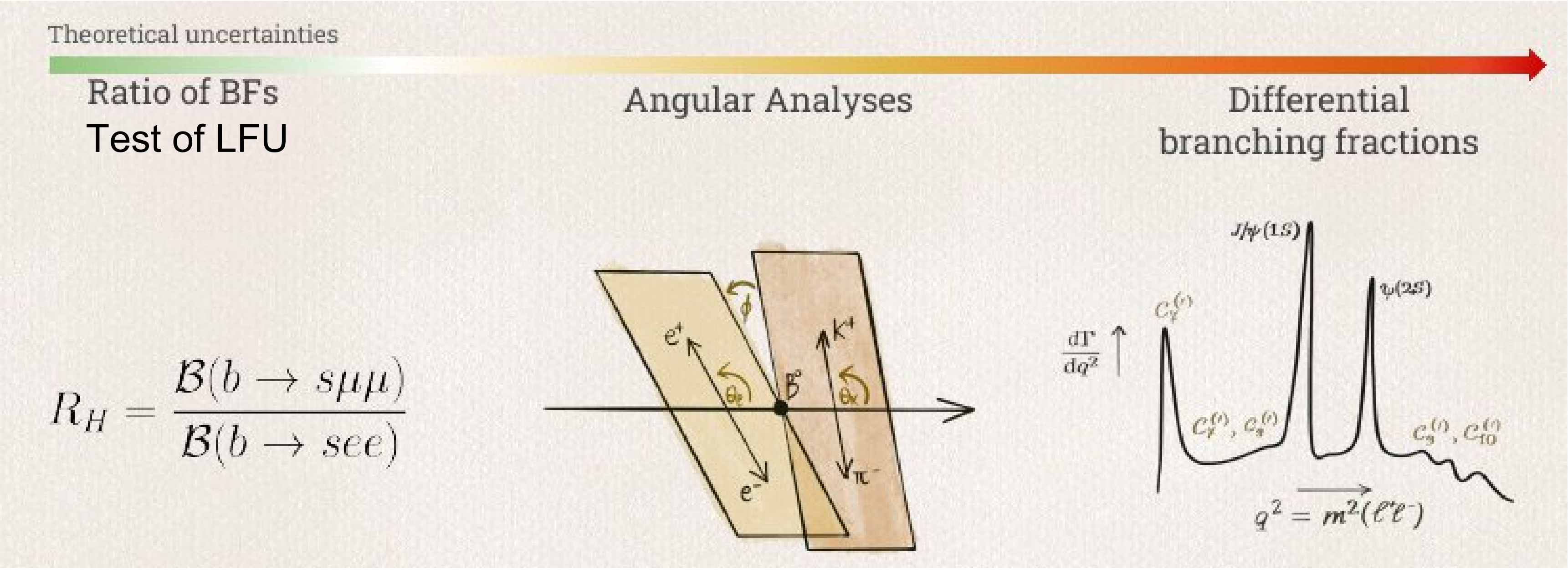
Pronounced enhancements at both kinematic thresholds

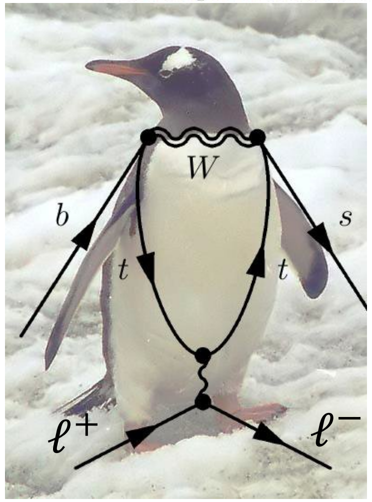
Observables in FCNC $b \to s(d)\ell\ell$ decays

Physics depends on $q^2 = m^2_{ll}$:
- Resonances (e.g. J/ψ, ϕ)
- Photon pole at low q^2
- Vector or axial vector current

T.Blake et al. arXiv:1606.00916





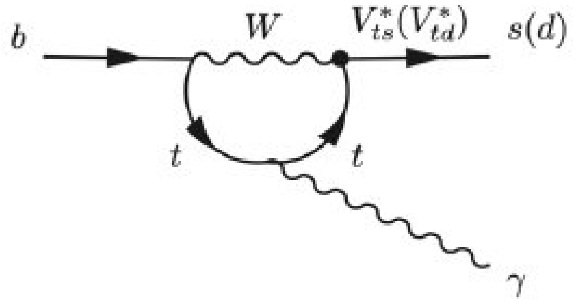


arXiv:2507.14401

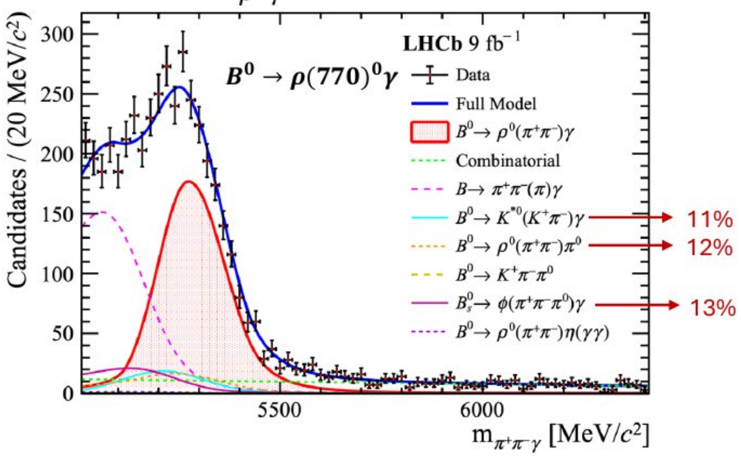
Radiative $B^0 \to \rho^0(770)\gamma$ decays

- Using full 9 fb^{-1} Runs1-2 data
- Normalization channel $B^0 \to K^{*0}\gamma$
- Offering independent & direct constraint on $|V_{td}/V_{ts}|$

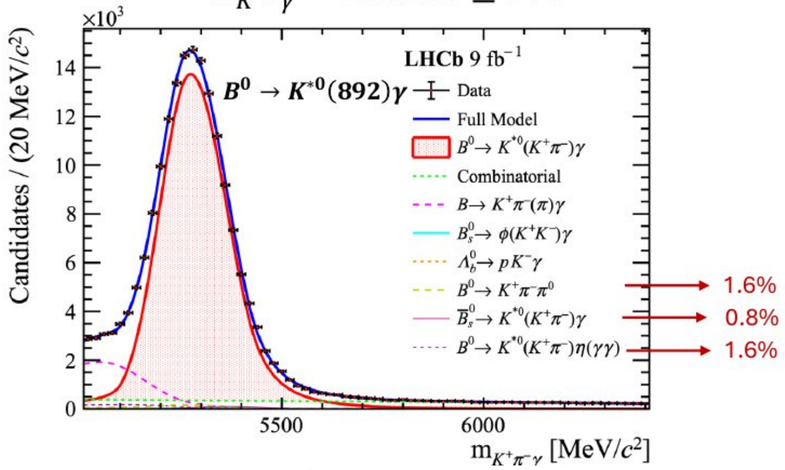
$$\frac{\mathcal{B}(B^0\to\rho^0(\pi^+\pi^-)\gamma)}{\mathcal{B}(B^0\to K^{*0}(K^+\pi^-)\gamma)} \propto |V_{td}/V_{ts}|^2$$



$N_{\rho^0\gamma} = 1917 \pm 71$



$N_{K^{*0}\gamma} = 148160 \pm 900$

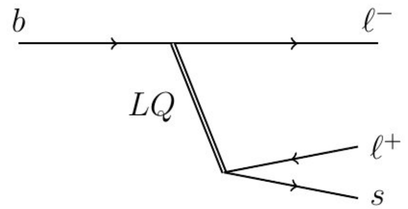


$$\frac{\mathcal{B}(B^0\to\rho(770)^0\gamma)}{\mathcal{B}(B^0\to K^*(892)^0\gamma)} = 0.0189 \pm \underset{\text{(stat.)}}{0.0007} \pm \underset{\text{(sys.)}}{0.0005},$$

$$\mathcal{B}(B^0\to\rho^0\gamma) = (7.9 \pm \underset{\text{(stat.)}}{0.3} \pm \underset{\text{(sys.)}}{0.2} \pm \underset{\text{(BF norm.)}}{0.2}) \times 10^{-7}$$

Most precise measurement to date

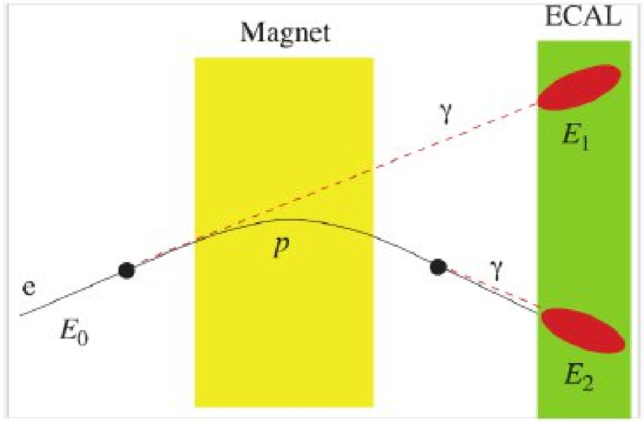
R(K$^{(*)}$) measurements @ LHCb

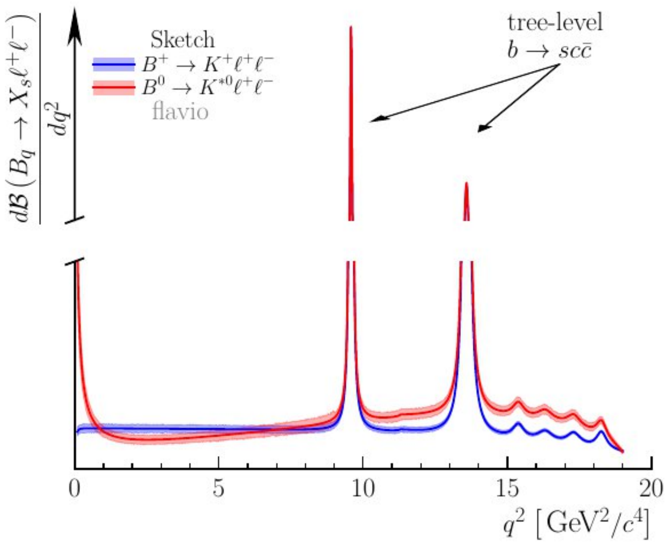


- Electrons & muons behave quite differently in the LHCb detector
- Lower efficiencies & worse resolution (energy loss) for electrons
- Double-ratio of branching fractions:

$$R_X = \frac{\mathcal{B}\left(B_q \to X_s \mu^+\mu^-\right)}{\mathcal{B}\left(B_q \to X_s J/\psi(\mu^+\mu^-)\right)} \cdot \frac{\mathcal{B}\left(B_q \to X_s J/\psi(e^+e^-)\right)}{\mathcal{B}\left(B_q \to X_s e^+e^-\right)}$$

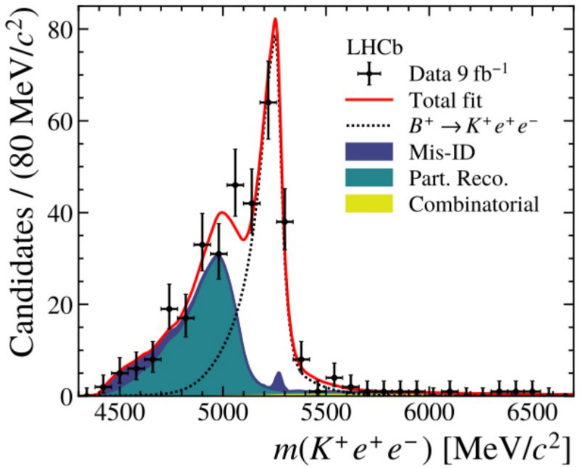
  - Most of systematic uncertainties cancel to 1st order
  - LFU in $J/\psi \to l^+l^-$ well established at ‰ level [BESIII, PRD 88, 032007 (2013)]
  - Validated in ψ(2S) mode

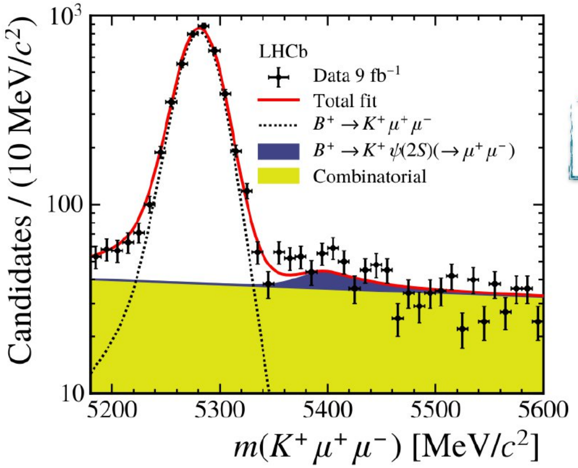




R(K) result at high q^2

- First LHCb result at high q^2 region above $\psi(2S)$ (q^2 > 14.3 GeV^2)
- Full Runs1-2 9 fb^{-1} analysis



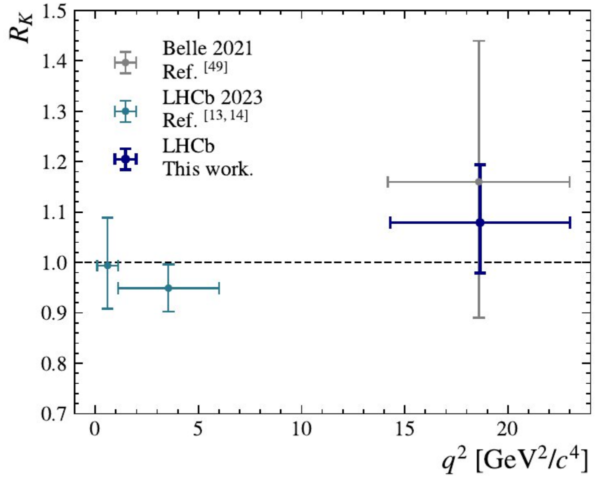


$$N(K^+\mu^+\mu^-) = 4008 \pm 71$$

Most precise to date:

$$R_K(q^2 > 14.3\ \mathrm{GeV}^2/c^4) = 1.08^{+0.11}_{-0.09}{}^{+0.04}_{-0.04}$$

Compatible with the SM

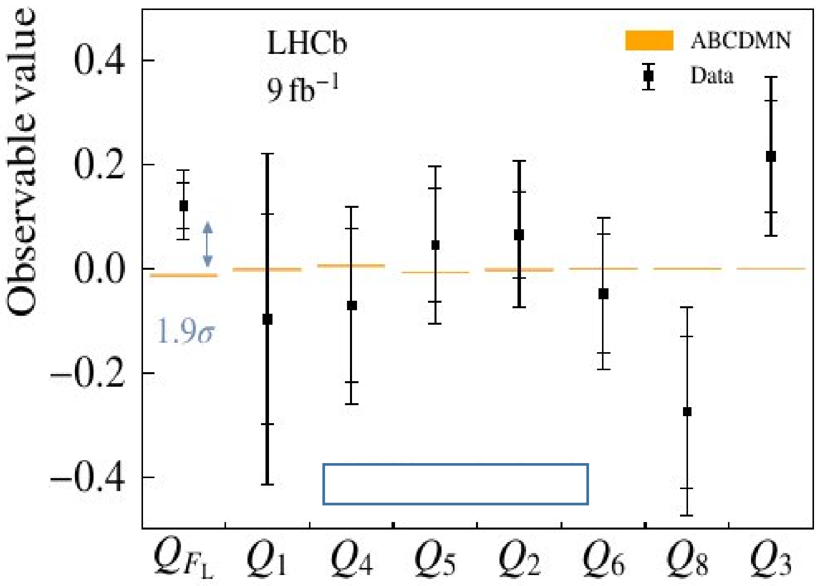


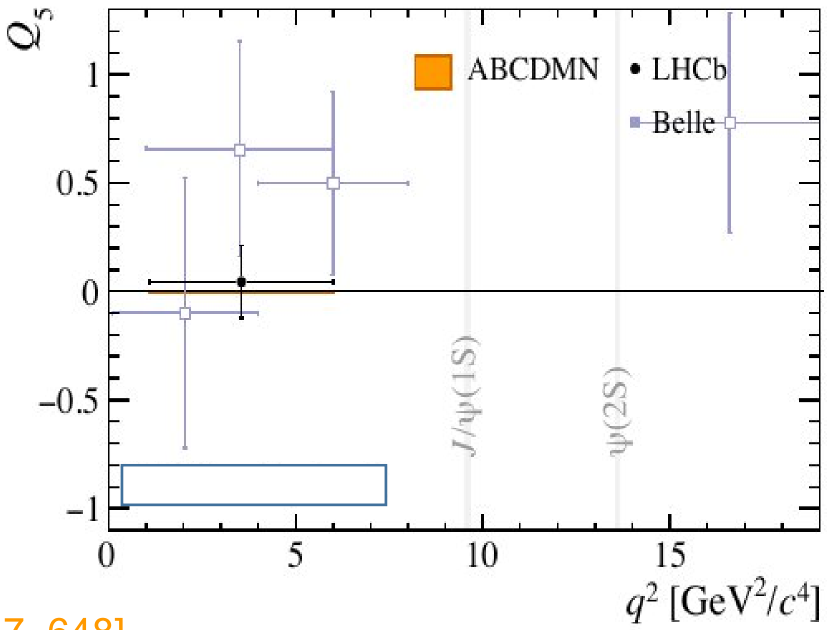
$$R_K = \frac{N(K^+\mu^+\mu^-)}{N(K^+e^+e^-)} \cdot \frac{\varepsilon(K^+e^+e^-)}{\varepsilon(K^+\mu^+\mu^-)} \cdot \frac{1}{r_{J/\psi}}$$

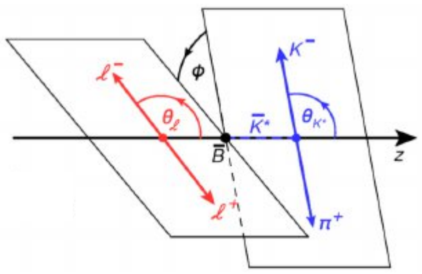
LFU in angular analysis of $B \to K^{*0} e^+ e^-$

- First angular analysis at central q^2 region
- Full Runs1-2 9 fb^{-1} analysis with 5D unbinned weighted fit
- LFU quantities derived by comparing e^+e^- to $\mu^+\mu^-$ results in [PRL 132 (2024) 131801]

$$Q_i = P_i^{(\mu)} - P_i^{(e)}$$







[M. Algueró et al., EPJC 83 (2023) 7, 648]

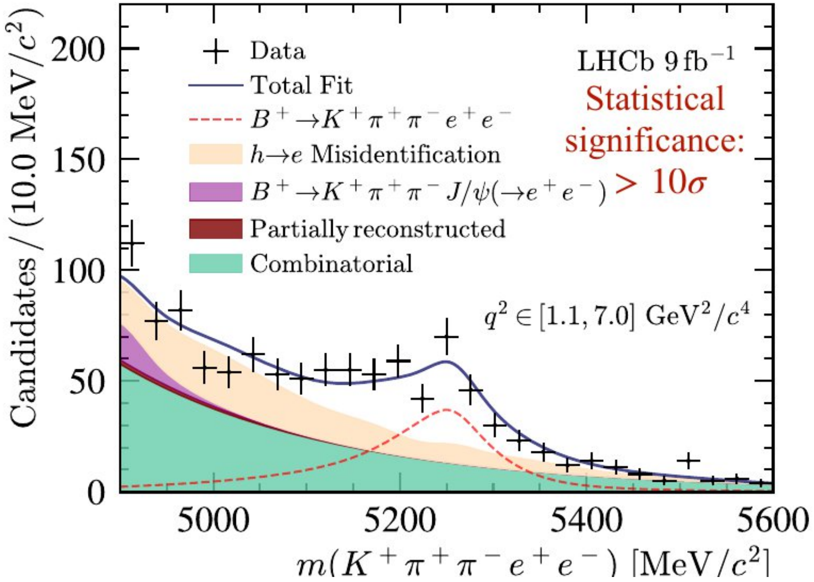
Results are all consistent with LFU conservation hypothesis

PRL 134 (2025) 181803

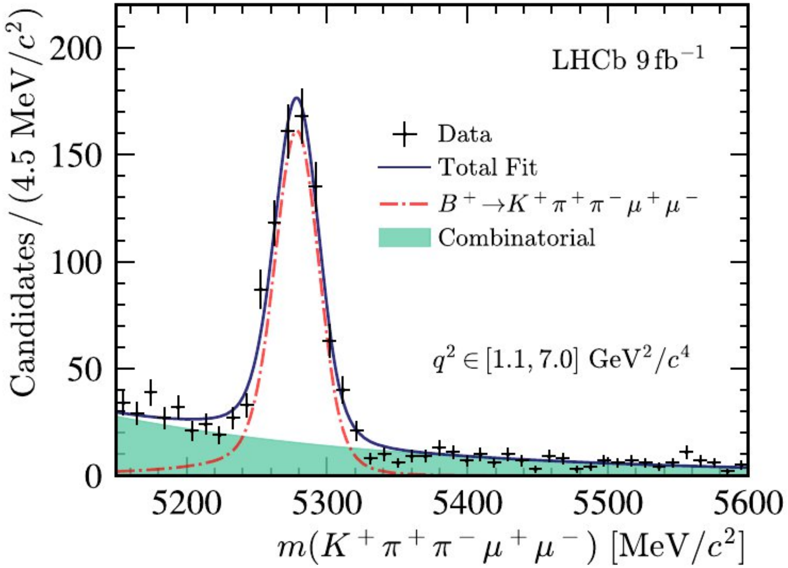
R($K\pi\pi$): LFU in $B \to K\pi\pi l^+ l^-$

- First LFU test in this channel, inclusive Kππ system
- In central q^2 region: $1.0 < q^2 < 7.0$ GeV^2
- First observation of $B^+ \to K^+\pi^+\pi^- e^+ e^-$
- Cross-checks: $r_{J/\psi} = 1.033 \pm 0.017, R_{\psi(2S)} = 1.040 \pm 0.030$

$$R^{-1}_{K\pi\pi} \equiv \frac{\frac{\mathcal{N}}{\varepsilon}(B^+ \to K^+\pi^+\pi^- e^+ e^-)}{\frac{\mathcal{N}}{\varepsilon}[B^+ \to K^+\pi^+\pi^- J/\psi\,(\to e^+ e^-)]} \Big/ \frac{\frac{\mathcal{N}}{\varepsilon}(B^+ \to K^+\pi^+\pi^- \mu^+ \mu^-)}{\frac{\mathcal{N}}{\varepsilon}[B^+ \to K^+\pi^+\pi^- J/\psi\,(\to \mu^+ \mu^-)]}$$



$\mathcal{N}(B^+ \to K^+\pi^+\pi^- e^+ e^-) = 264 \pm 21$



$\mathcal{N}(B^+ \to K^+\pi^+\pi^- \mu^+ \mu^-) = 731 \pm 31$

$$\boxed{R^{-1}_{K\pi\pi} = 1.31^{+0.18}_{-0.17}\,(\text{stat})\,^{+0.12}_{-0.09}\,(\text{syst})}$$

- Compatible with the SM

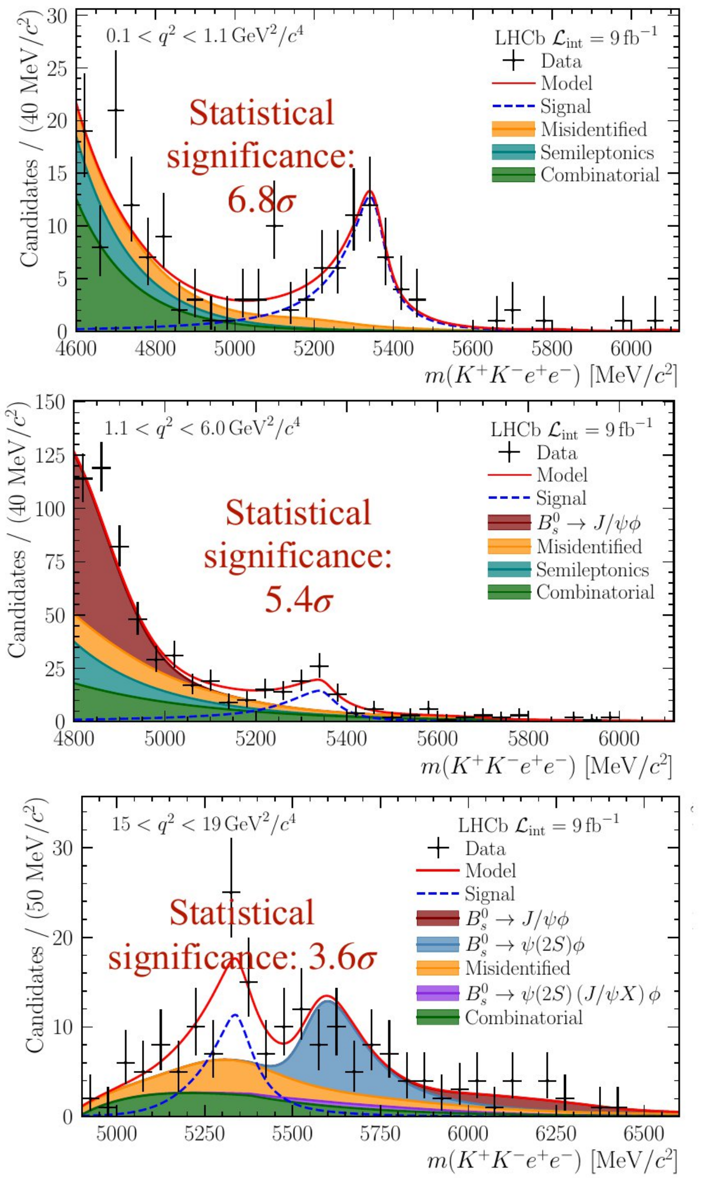
PRL 134 (2025) 121803

R(ϕ): LFU in $B_s^0 \to \phi l^+ l^-$

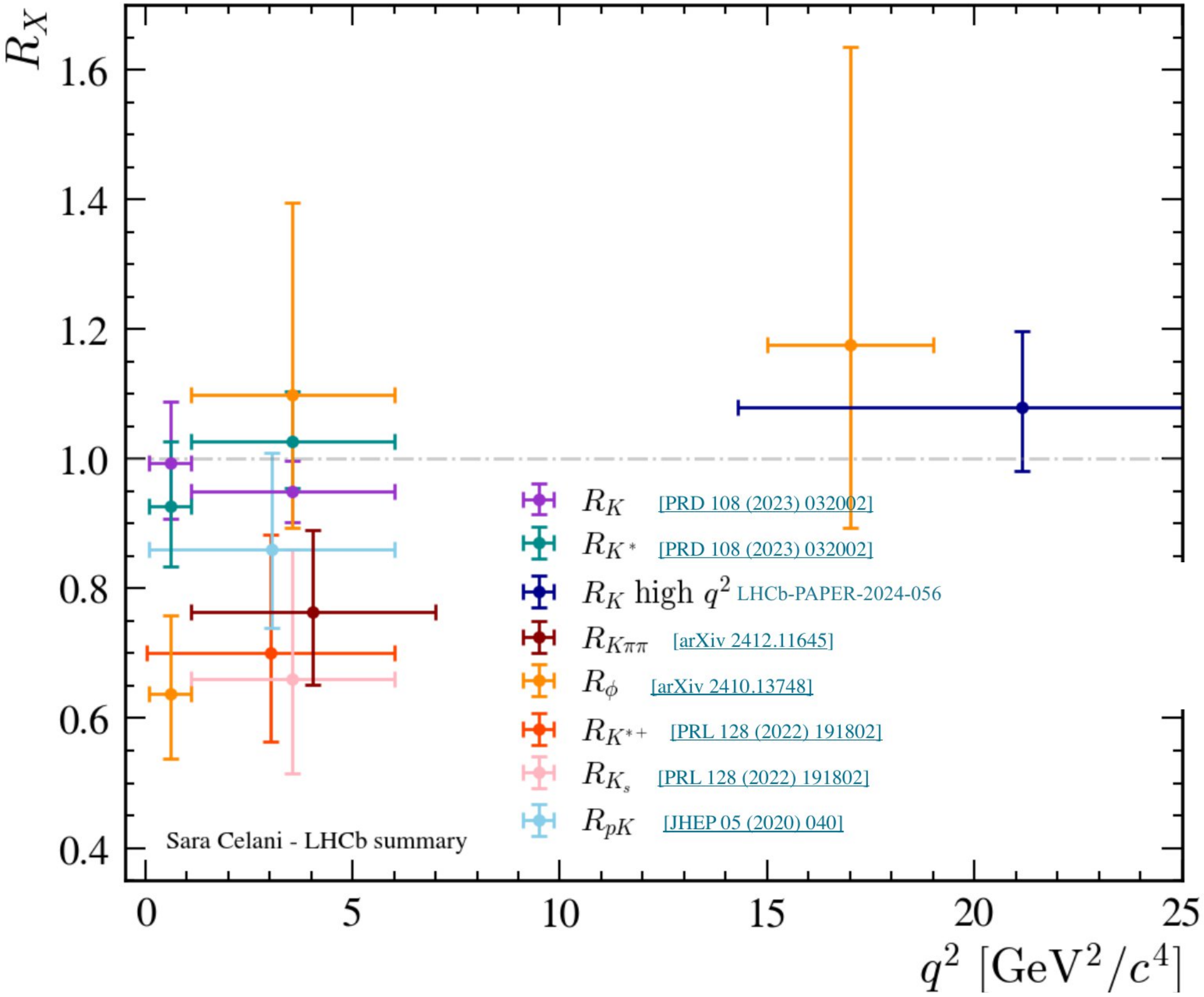
- First LFU test for B_s^0 decays
- In three q^2 regions: [0.1, 1.1], [1.1, 6.0], [15, 19] GeV^2
- Cross-checks: $r_{J/\psi} = 0.997 \pm 0.013,\ R_{\psi(2S)} = 1.010 \pm 0.026$
- Results in agreement with SM:

$q^2\ [\mathrm{GeV}^2/c^4]$	R_ϕ^{-1}
$0.1 < q^2 < 1.1$	$1.57\,^{+0.28}_{-0.25} \pm 0.05$
$1.1 < q^2 < 6.0$	$0.91\,^{+0.20}_{-0.19} \pm 0.05$
$15.0 < q^2 < 19.0$	$0.85\,^{+0.24}_{-0.23} \pm 0.10$

$$R_\phi = \left(\frac{\mathcal{B}(B_s^0 \to \phi\mu^+\mu^-)}{\mathcal{B}(B_s^0 \to J/\psi(\to \mu^+\mu^-)\phi)}\right) \Big/ \left(\frac{\mathcal{B}(B_s^0 \to \phi e^+e^-)}{\mathcal{B}(B_s^0 \to J/\psi(\to e^+e^-)\phi)}\right)$$



Summary of LHCb FCNC LFU results



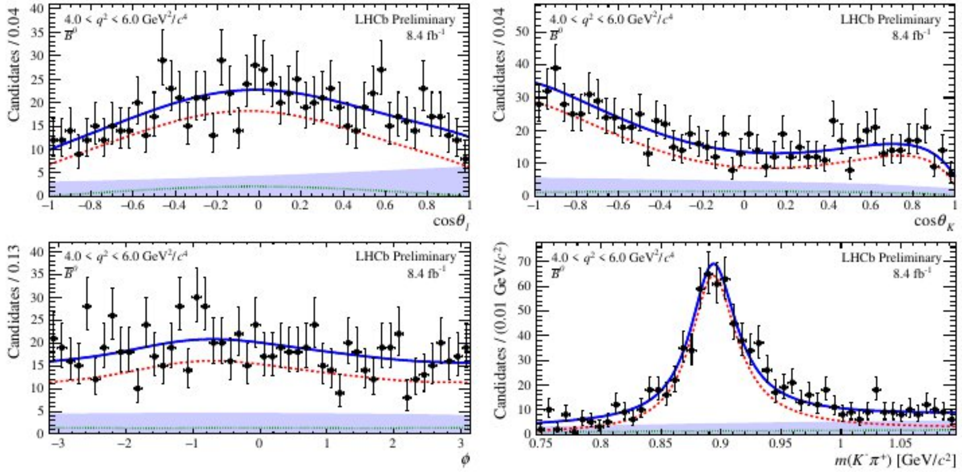
Moriond QCD 2025 - Flavour changing neutral currents decay at LHCb

LHCb-PAPER-2025-041
In prep.

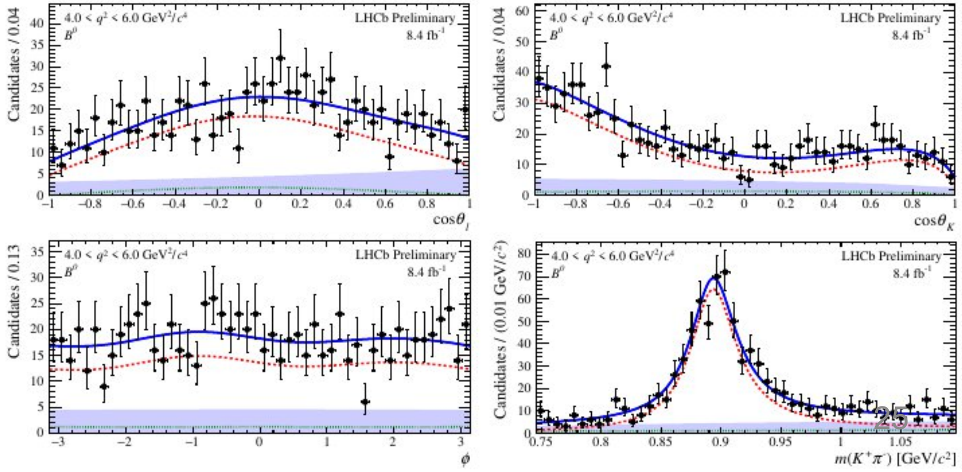
Legacy Runs1-2 $B^0 \rightarrow K^{*0}\mu^+\mu^-$ measurement

- 5D (3 decay angles, m_B, $m_{K\pi}$) unbinned ML fit in bins of q^2
  - Improved selection, more observables (CPV, dBF)
  - Finer q^2 binning
  - Lepton mass accounted for
  - Full suite of S-wave and P-/S-wave interference observables
  - 2x statistics
  - Data split into B^0 and $\overline{B}^0$, and fit simultaneously

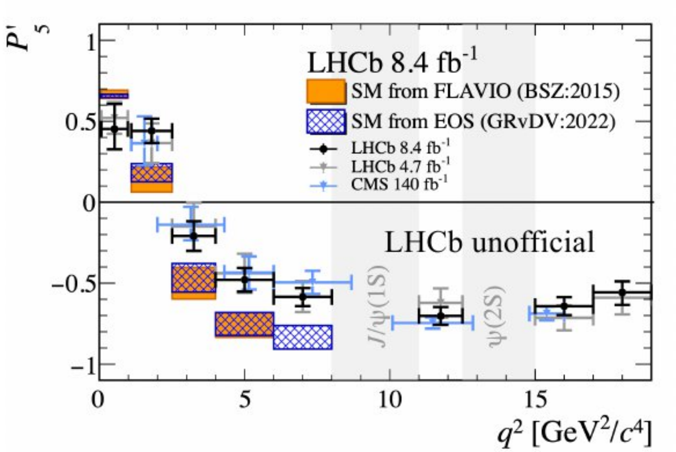
$\overline{B}^0$:

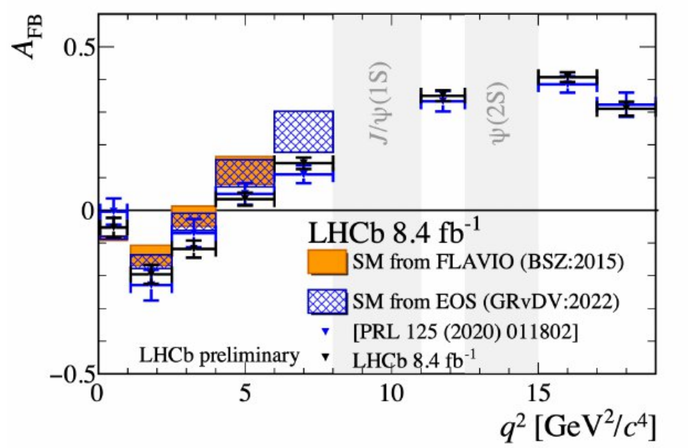


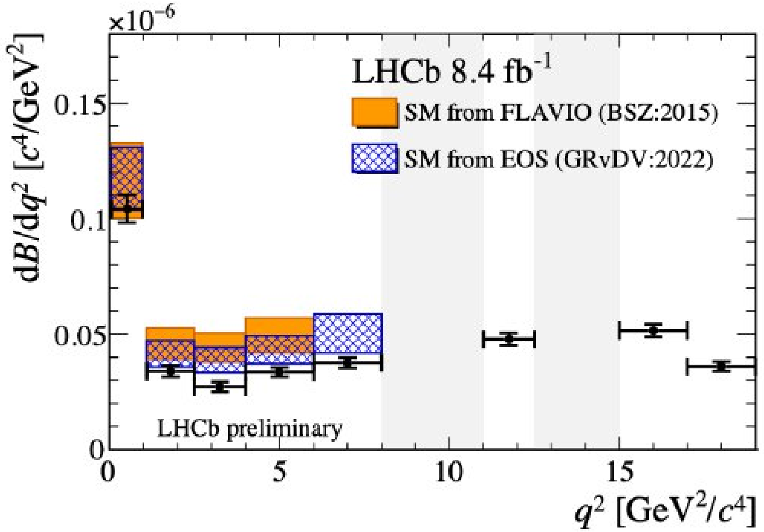
B^0:



Legacy Runs1-2 $B^0 \to K^{*0}\mu^+\mu^-$ measurement



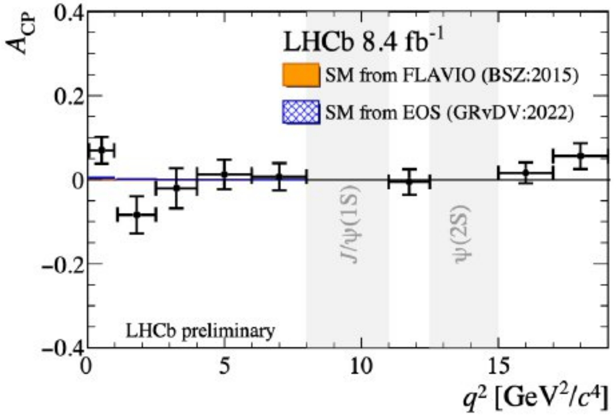


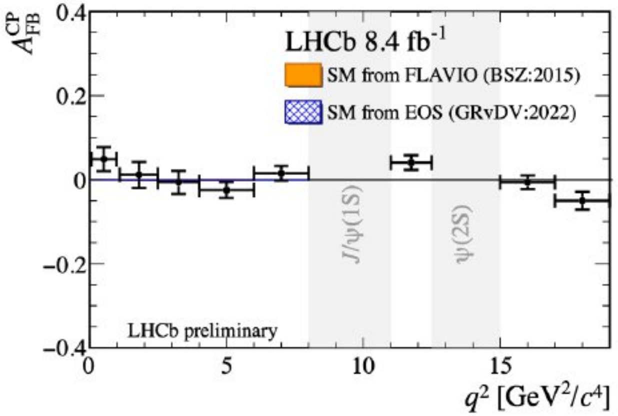


- Results in P_5' excellent agreement with both CMS and previous LHCb
- Deviations of 2.6 and 2.7 σ in 4-6 and 6-8 GeV^2 bins

The forward-backward asymmetry, A_{FB}, also now shows marked disagreement with improved statistics

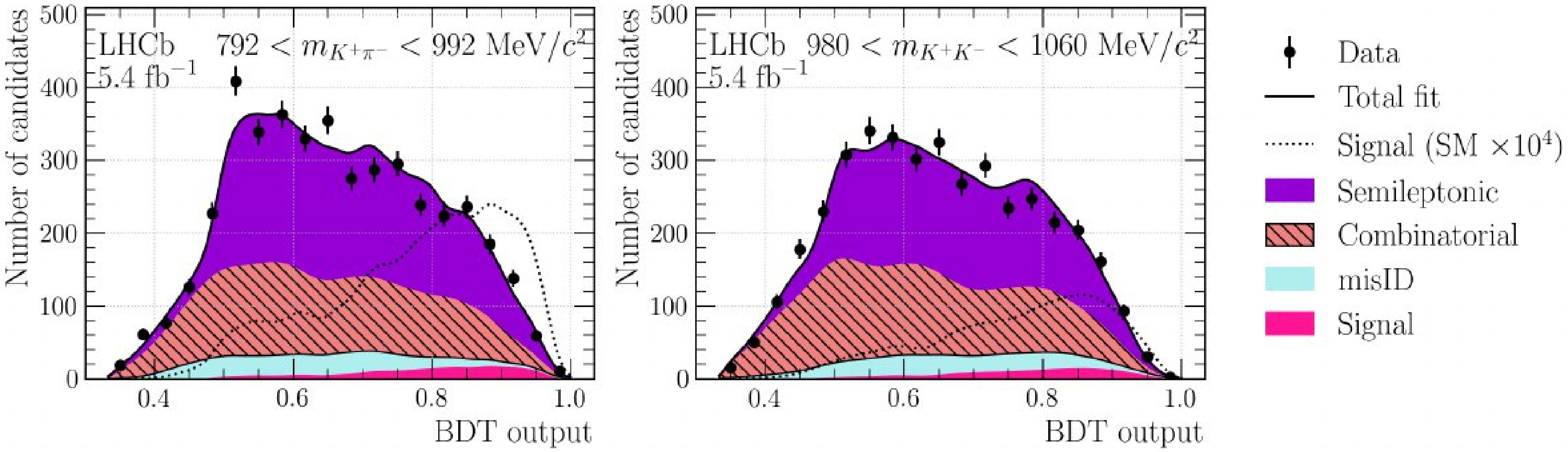
- The branching fraction is consistently below SM predictions





Search for $B^0 \to K^+\pi^-\tau^+\tau^-$ & $B_s^0 \to K^+K^-\tau^+\tau^-$

- Using Run2 5.4 fb^{-1} data
- Reconstructing taus with muonic channel
- Decays are searched in bins of dihadron masses



Searches in the lowest Kπ and KK bins

Search for $B^0 \to K^+\pi^-\tau^+\tau^-$ & $B_s^0 \to K^+K^-\tau^+\tau^-$

- Using Run2 5.4 fb^{-1} data
- Reconstructing taus with muonic channel
- Decays are searched in bins of dihadron masses
- No signal founds, upper limits are set:

$$\mathcal{B}(B^0 \to K^{*0}\tau^+\tau^-) < 2.8 \times 10^{-4}\ (2.5 \times 10^{-4}) \text{ at } 95\%\ (90\%) \text{ CL},$$
$$\mathcal{B}(B_s^0 \to \phi\tau^+\tau^-) < 4.7 \times 10^{-4}\ (4.1 \times 10^{-4}) \text{ at } 95\%\ (90\%) \text{ CL}.$$

One order of magnitude improvement!

First search!

Upper limit on the shift Δ in the $\mathcal{C}_{9(10)}^{\tau\tau}$ Wilson coefficient at 90% and 95% CL.

Confidence level	$B^0 \to K^+\pi^-\tau^+\tau^-$	$B_s^0 \to K^+K^-\tau^+\tau^-$
90%	2.5×10^4	4.5×10^4
95%	2.9×10^4	5.2×10^4

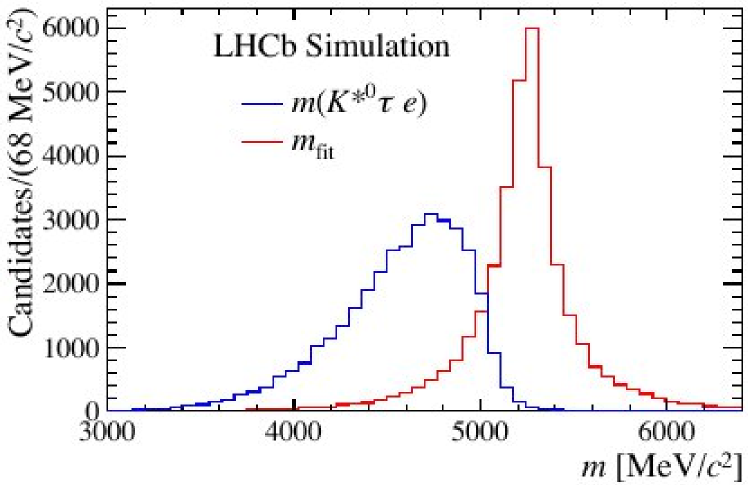
$$\mathcal{C}_{9(10)}^{\tau\tau} = \mathcal{C}_{9(10)}^{\mathrm{NP}} - (+)\Delta$$

arXiv:2506.15347

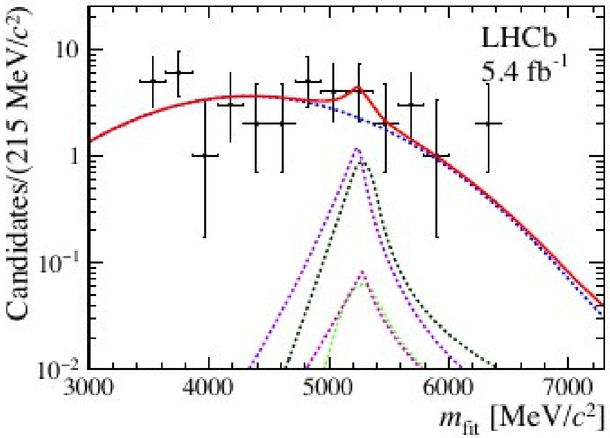
Search for LFV decay $B^0 \to K^{*0}\tau^\pm e^\mp$

- Lepton Flavour Violating decays would be enabled/enhanced by leptoquarks or Z' models
- New search for the lepton-flavour-violating decays $B^0 \to K^{*0}\tau^\pm e^\mp$ at LHCb
  - first direct LFV search at LHCb with $e\tau$ combination (Run2 data)
  - New Physics models predict branching ratio up to 10^{-6} for this decay
  - 3-prong τ hadronic decay $\Rightarrow$ decay vertex available, kinematic constraints with dedicated Decay Tree Fit gives much improved resolution!
  - $B^0 \to D^- D_s^+$ ($D^- \to K\pi\pi$, $D_s^+ \to KK\pi$) used as normalisation and control channel, and 3 multivariate discriminators to suppress background:
    - topologies of the signal decays and the combinatorial background
    - Isolation (simulation + Same Sign data)
    - Charm vs τ-lepton rejection
  - Limits on two decay channels at 90%(95%) CL:

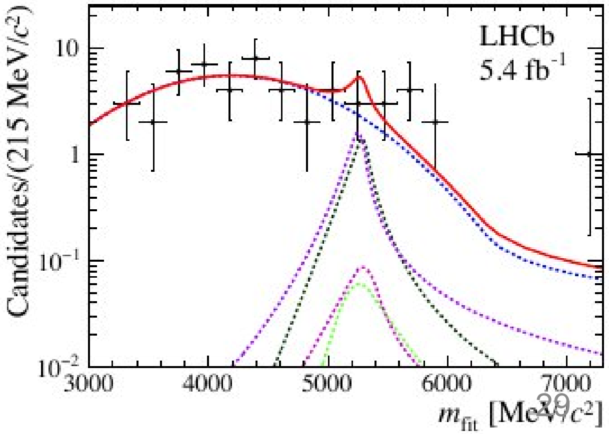
$$\mathscr{B}(B^0 \to K^{*0}\tau^- e^+) < 5.9(7.1) \times 10^{-6}$$
$$\mathscr{B}(B^0 \to K^{*0}\tau^+ e^-) < 4.9(5.9) \times 10^{-6}$$

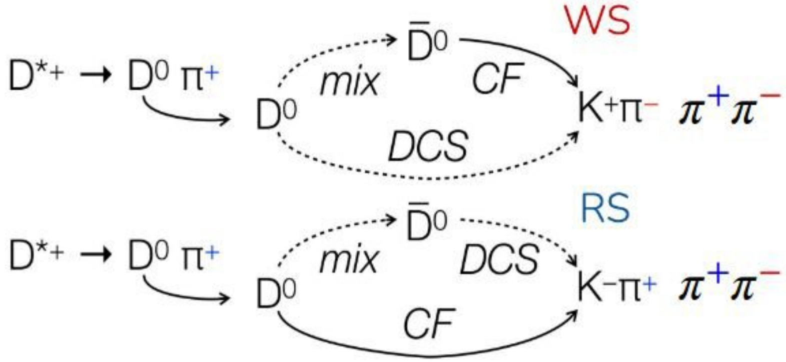


$B^0 \to K^{*0}\tau^- e^+$



$B^0 \to K^{*0}\tau^+ e^-$

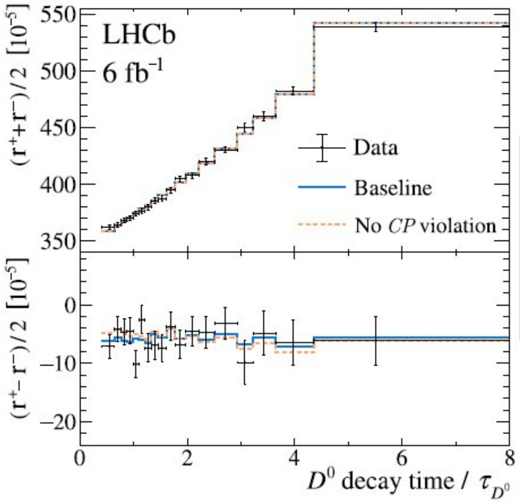




Charm mixing & CPV

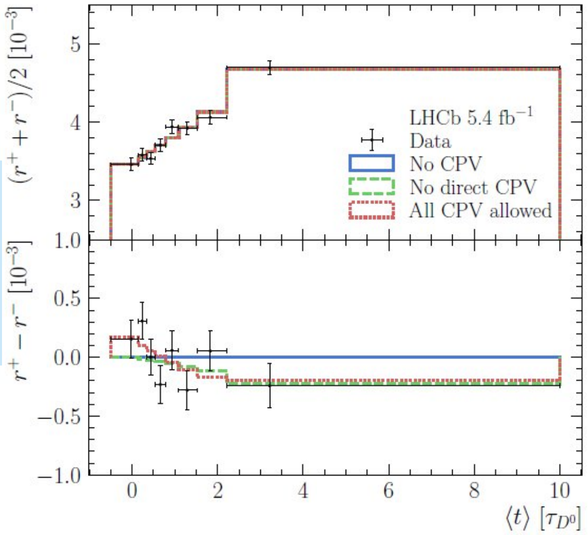
- Measure neutral D mixing & CPV using RS/WS $D^0 \to K^{\mp}\pi^{\pm}(\pi^+\pi^-)$
- No evidence of CPV in mixing or decay found

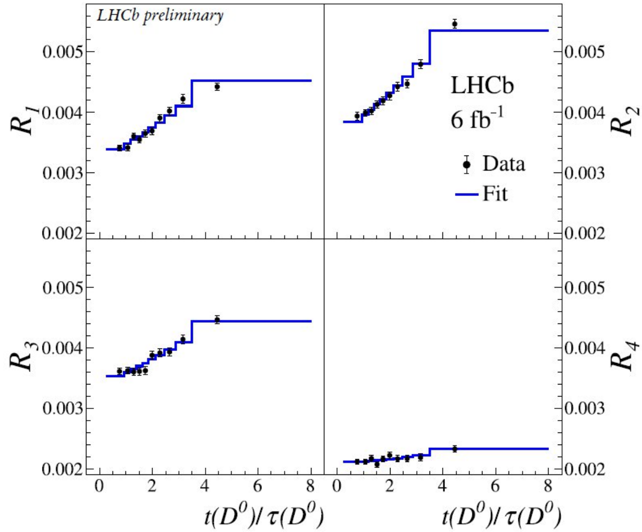
$R_{K\pi}$	$(343.1 \pm 2.0) \times 10^{-5}$
$c_{K\pi}$	$(51.4 \pm 3.5) \times 10^{-4}$
$c'_{K\pi}$	$(13.1 \pm 3.7) \times 10^{-6}$
$A_{K\pi}$	$(-7.1 \pm 6.0) \times 10^{-3}$
$\Delta c_{K\pi}$	$(3.0 \pm 3.6) \times 10^{-4}$
$\Delta c'_{K\pi}$	$(-1.9 \pm 3.8) \times 10^{-6}$



R_D^+	$(355.2 \pm 7.9 \pm 2.3) \times 10^{-5}$
y'^+	$(3.6 \pm 2.2 \pm 0.3) \times 10^{-3}$
$(x'^+)^2$	$(1.1 \pm 1.6 \pm 0.1) \times 10^{-4}$
R_D^-	$(339.1 \pm 7.9 \pm 2.3) \times 10^{-5}$
y'^-	$(8.1 \pm 2.3 \pm 0.3) \times 10^{-3}$
$(x'^-)^2$	$(-1.1 \pm 1.9 \pm 0.1) \times 10^{-4}$

Lower stat. but better coverage at small t





Prompt $D^0 \to K^{\mp}\pi^{\pm}$
PRD 111 (2025) 012001

Semileptonic $D^0 \to K^{\mp}\pi^{\pm}$
JHEP 03 (2025) 149

Prompt $D^0 \to K3\pi$
LHCb-PAPER-2025-029 in prep.

BESIII results on hadronic parameters fundamental

CPV in $\Lambda_c^+ \to p\mu^+\mu^-$

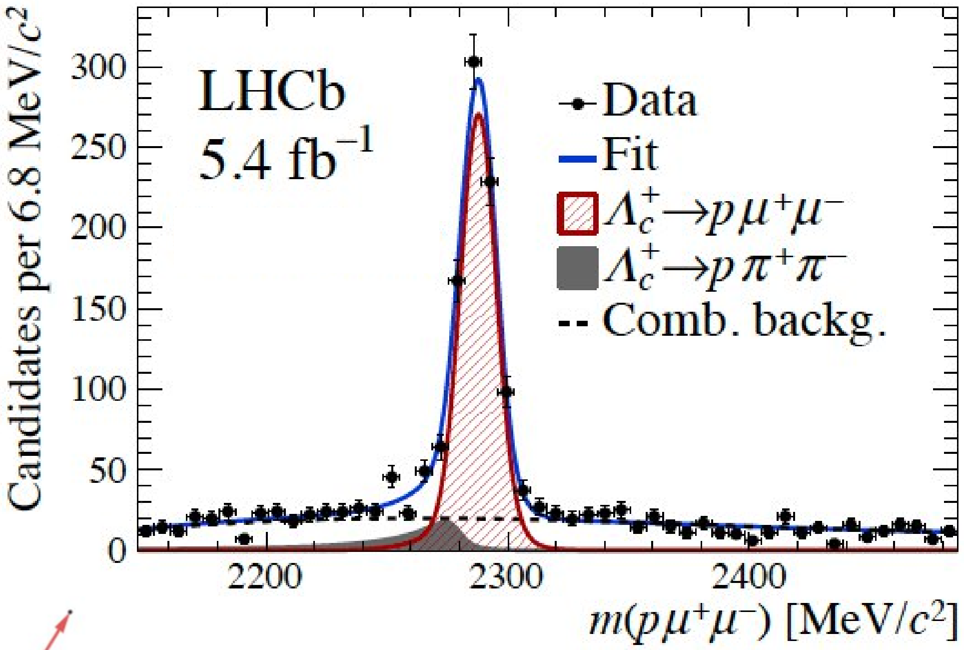
- Using Run 2 5.4 fb^{-1} data
- Control sample: $\Lambda_c^+ \to pK_S^0$
- Forward-backward asymmetry:

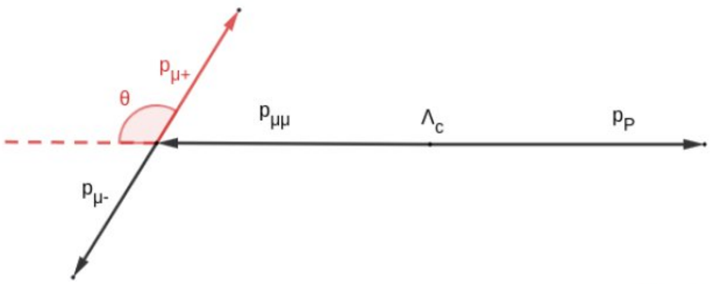
$$A_{FB} = \frac{N(\cos\theta > 0) - N(\cos\theta < 0)}{N(\cos\theta > 0) + N(\cos\theta < 0)}$$

- Final results:

$$A_{CP} = -1.1 \pm 4.0 \pm 0.5\%$$
$$\Sigma A_{\mathrm{FB}} = +3.9 \pm 4.0 \pm 0.6\%$$
$$\Delta A_{\mathrm{FB}} = +3.1 \pm 4.0 \pm 0.4\%$$

No CPV observed





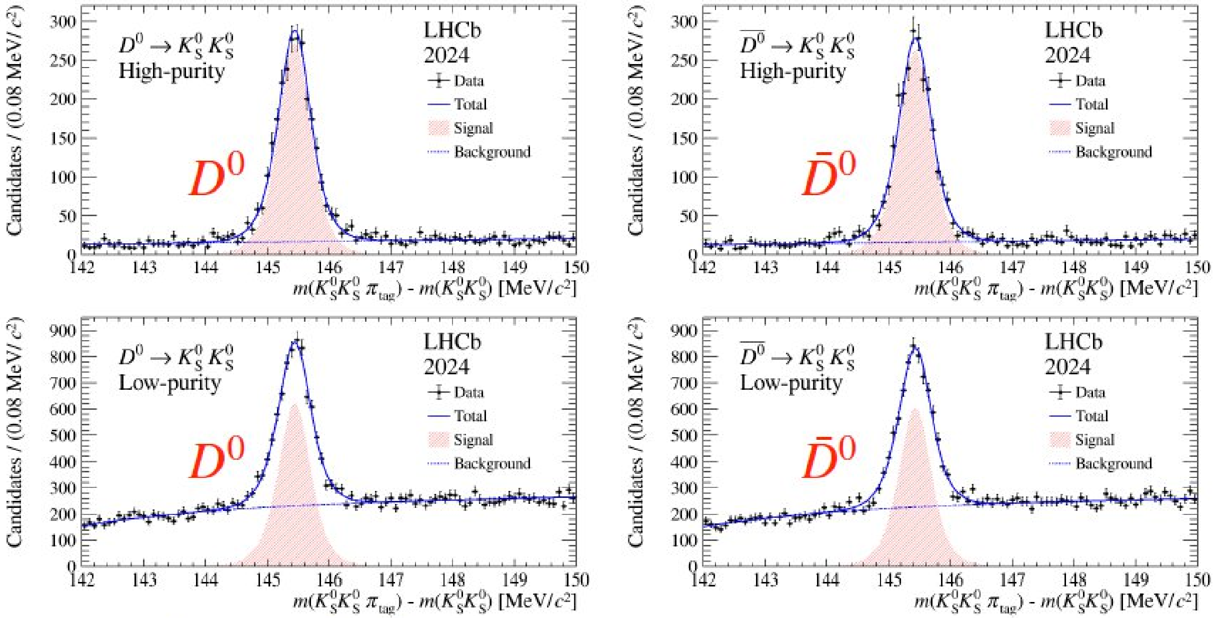
$$\Sigma A_{FB} = \frac{1}{2}\left(A_{FB}^{\Lambda_c^+} + A_{FB}^{\bar{\Lambda}_c^-}\right)$$

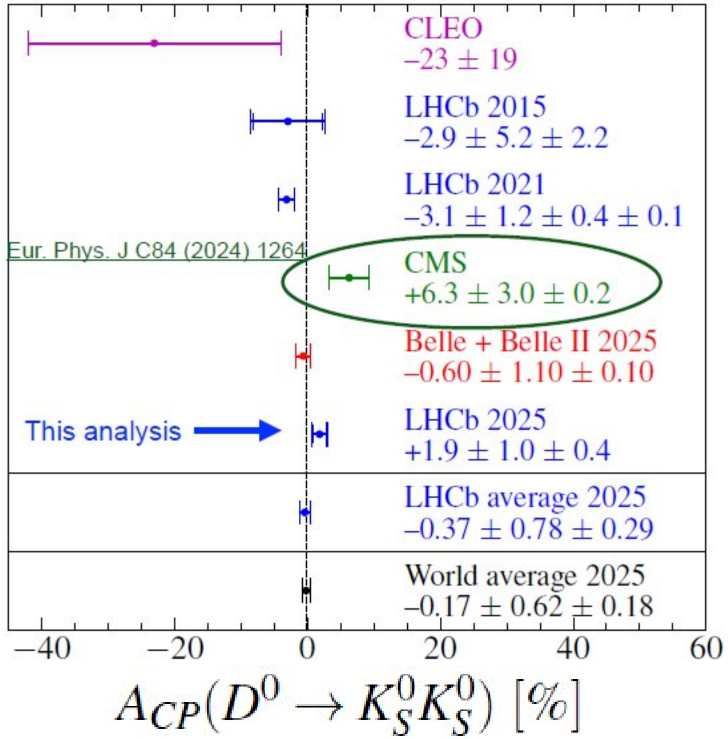
$$\Delta A_{FB} = \frac{1}{2}\left(A_{FB}^{\Lambda_c^+} - A_{FB}^{\bar{\Lambda}_c^-}\right)$$

CPV in $D^0 \to K_S^0 K_S^0$

- $D^0/\overline{D}^0$ tagged via $D^{*+} \to D^0 \pi_s^+$
- $D^0 \to K_S^0 \pi^+ \pi^-$ used as control mode to cancel tagging/production asymmetries
- First LHCb result with 2024 data! Total signal yield: 15,676 ± 229

Define two categories with different purities according to a MVA classifier

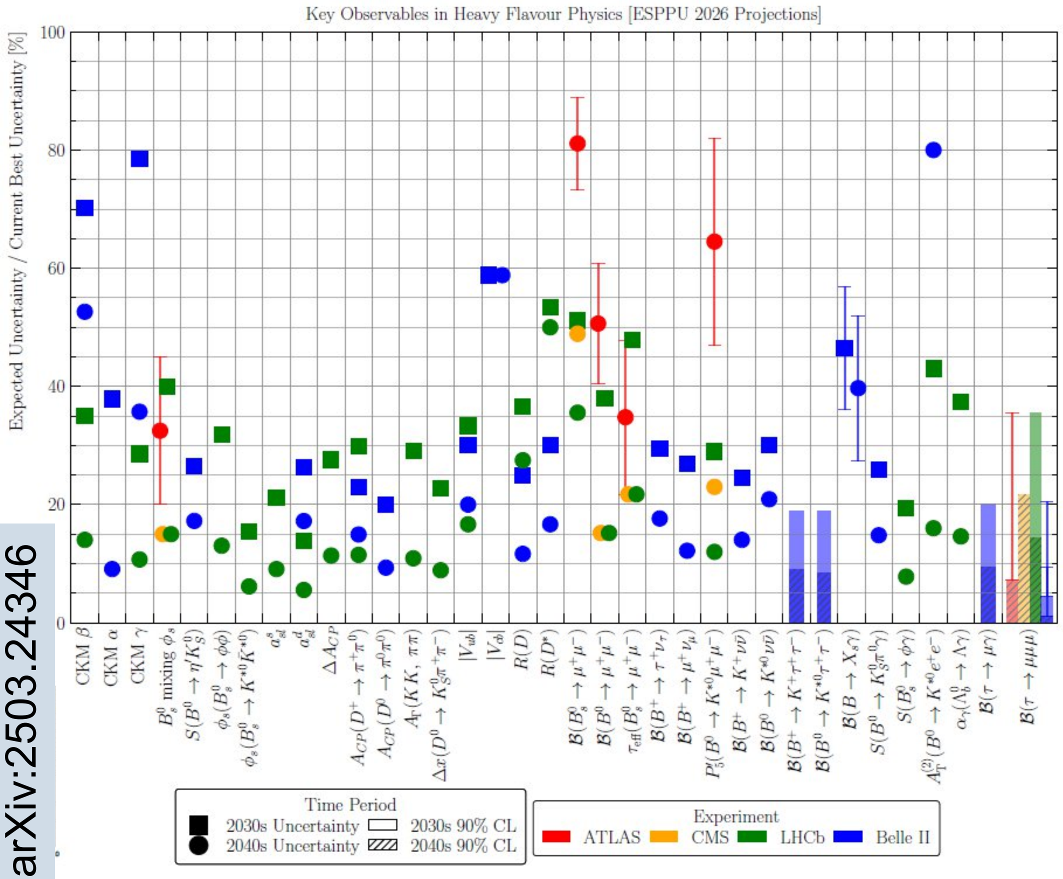




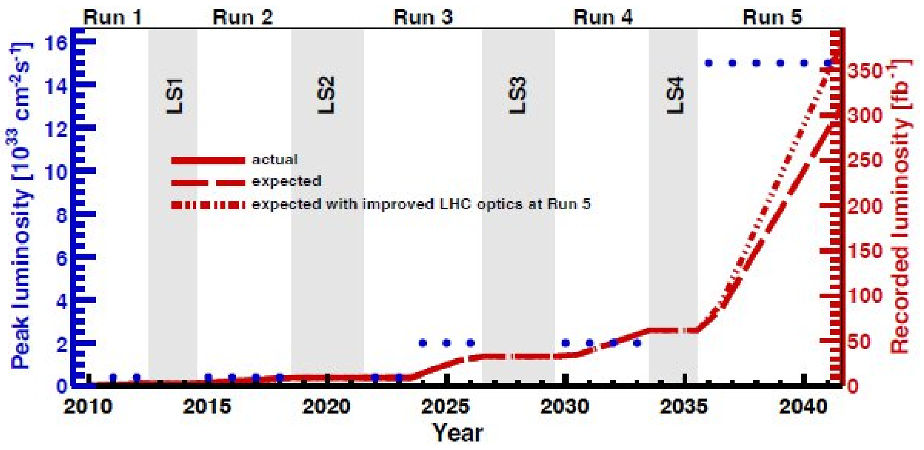
$$A_{CP}(D^0 \to K_S^0 K_S^0) = (1.86 \pm 1.04 \pm 0.41)\,\%$$

Summary & outlook

- Broad & rich flavor physics programs at LHCb
- Not included: hadron spec., semileptonic B decays, strange hadron decays, etc.
- Many first observations & precision measurements such as CPV in baryonic decay
- So far, no surprises, but tensions still persist (C_9?)
- Many new results on the way, stay tuned for CLHCP & implication workshop!
- Now a new detector and improved hadron trigger: higher efficiency per fb^{-1}
- And we will have Run4 and Upgrade-II!
  - 50 fb^{-1} by 2033, > 300 fb^{-1} by 2041



arXiv:2503.24346

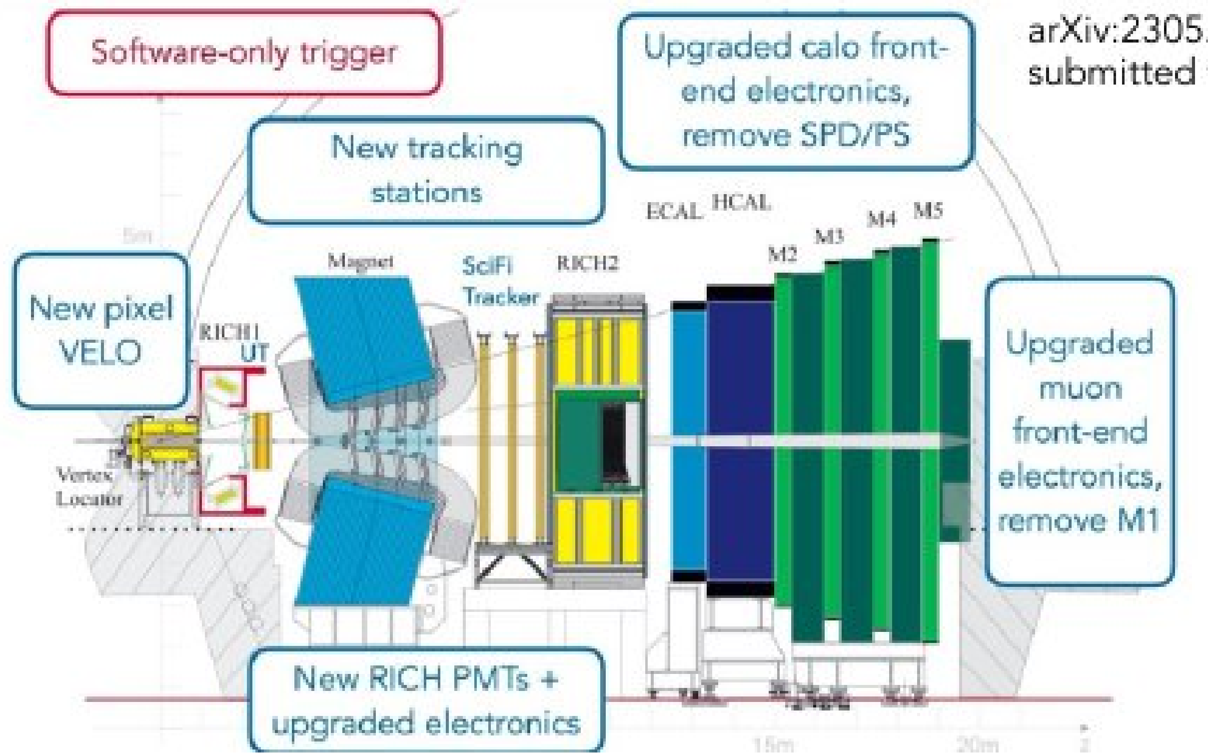


Backup Slides

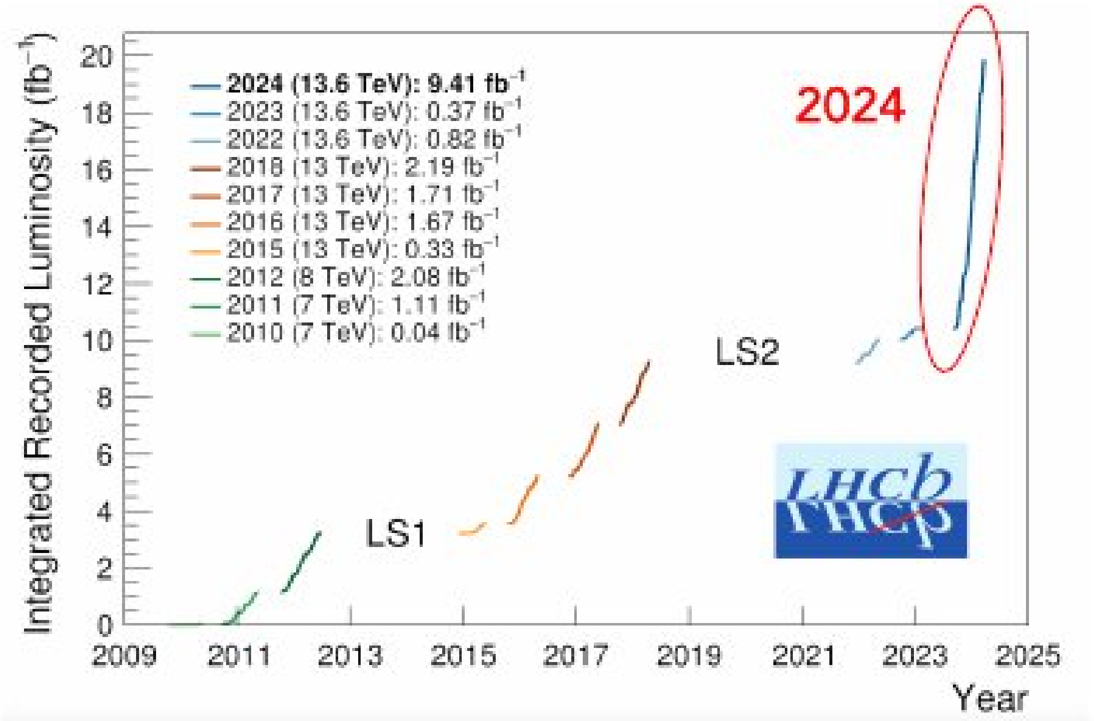
LHCb-Upgrade I

Luminosity x5 wrt Run2
5.5 visible interactions/crossing
Higher track multiplicity from ~<70> to ~<180>)

No more hardware trigger (full detector readout at 40 MHz)
Tracking & PID detectors modified/replaced
Higher granularity



arXiv:2305.10515, submitted to JINST

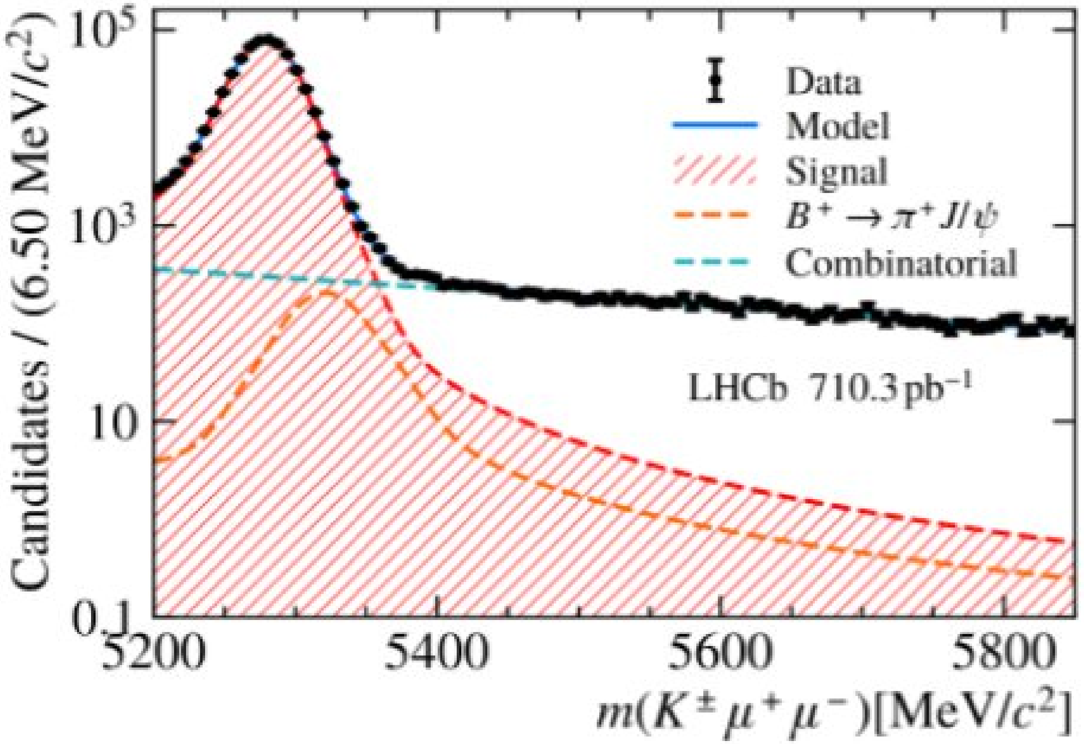


In January 2023, a loss of control of the LHC primary vacuum system
⇒ plastic deformation of the RF foil separating VELO from LHC.
⇒ significant impact on 2023 physics programme

2022 – 2023 : commissioning and understanding the new detector

2024 : a lot of data !

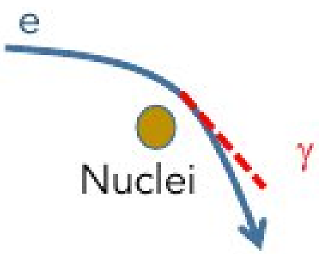
$1\,\mathrm{fb}^{-1}$ collected during October 2024

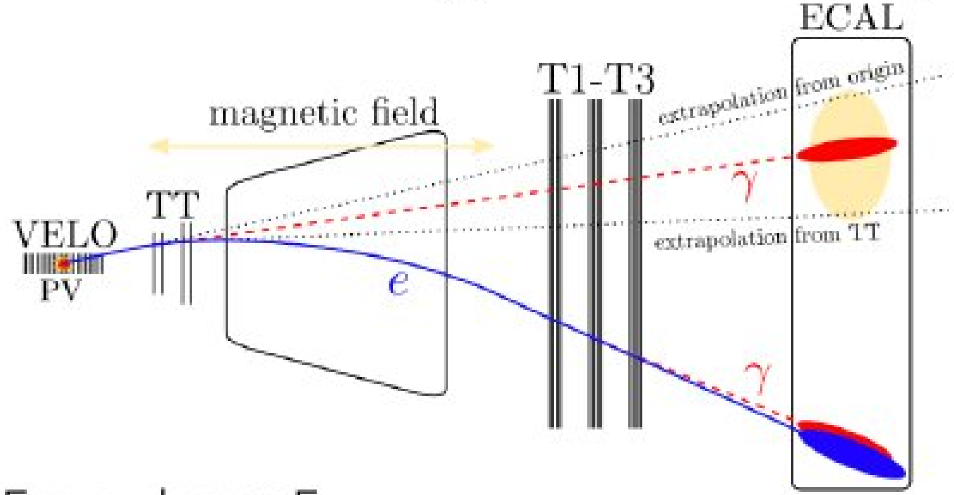


LHCb_TDR_023

Observable	Current LHCb (up to $9\,\mathrm{fb}^{-1}$)		Upgrade I ($23\,\mathrm{fb}^{-1}$)	Upgrade I ($50\,\mathrm{fb}^{-1}$)	Upgrade II ($300\,\mathrm{fb}^{-1}$)
CKM tests					
γ ($B \to DK$, *etc.*)	$4°$	[9,10]	$1.5°$	$1°$	$0.35°$
ϕ_s ($B_s^0 \to J/\psi\phi$)	32 mrad	[8]	14 mrad	10 mrad	4 mrad
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$ ($\Lambda_b^0 \to p\mu^-\overline{\nu}_\mu$, *etc.*)	6%	[29,30]	3%	2%	1%
a_{sl}^d ($B^0 \to D^-\mu^+\nu_\mu$)	36×10^{-4}	[34]	8×10^{-4}	5×10^{-4}	2×10^{-4}
a_{sl}^s ($B_s^0 \to D_s^-\mu^+\nu_\mu$)	33×10^{-4}	[35]	10×10^{-4}	7×10^{-4}	3×10^{-4}
Charm					
ΔA_{CP} ($D^0 \to K^+K^-, \pi^+\pi^-$)	29×10^{-5}	[5]	13×10^{-5}	8×10^{-5}	3.3×10^{-5}
A_Γ ($D^0 \to K^+K^-, \pi^+\pi^-$)	11×10^{-5}	[38]	5×10^{-5}	3.2×10^{-5}	1.2×10^{-5}
Δx ($D^0 \to K_S^0\pi^+\pi^-$)	18×10^{-5}	[37]	6.3×10^{-5}	4.1×10^{-5}	1.6×10^{-5}
Rare Decays					
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	69%	[40,41]	41%	27%	11%
$S_{\mu\mu}$ ($B_s^0 \to \mu^+\mu^-$)	—		—	—	0.2
$A_{\mathrm{T}}^{(2)}$ ($B^0 \to K^{*0}e^+e^-$)	0.10	[52]	0.060	0.043	0.016
$A_{\mathrm{T}}^{\mathrm{Im}}$ ($B^0 \to K^{*0}e^+e^-$)	0.10	[52]	0.060	0.043	0.016
$\mathcal{A}_{\phi\gamma}^{\Delta\Gamma}(B_s^0 \to \phi\gamma)$	$^{+0.41}_{-0.44}$	[51]	0.124	0.083	0.033
$S_{\phi\gamma}(B_s^0 \to \phi\gamma)$	0.32	[51]	0.093	0.062	0.025
$\alpha_\gamma(\Lambda_b^0 \to \Lambda\gamma)$	$^{+0.17}_{-0.29}$	[53]	0.148	0.097	0.038
Lepton Universality Tests					
R_K ($B^+ \to K^+\ell^+\ell^-$)	0.044	[12]	0.025	0.017	0.007
R_{K^*} ($B^0 \to K^{*0}\ell^+\ell^-$)	0.12	[61]	0.034	0.022	0.009
$R(D^*)$ ($B^0 \to D^{*-}\ell^+\nu_\ell$)	0.026	[62,64]	0.007	0.005	0.002

Bremsstrahlung emission is significant for electrons





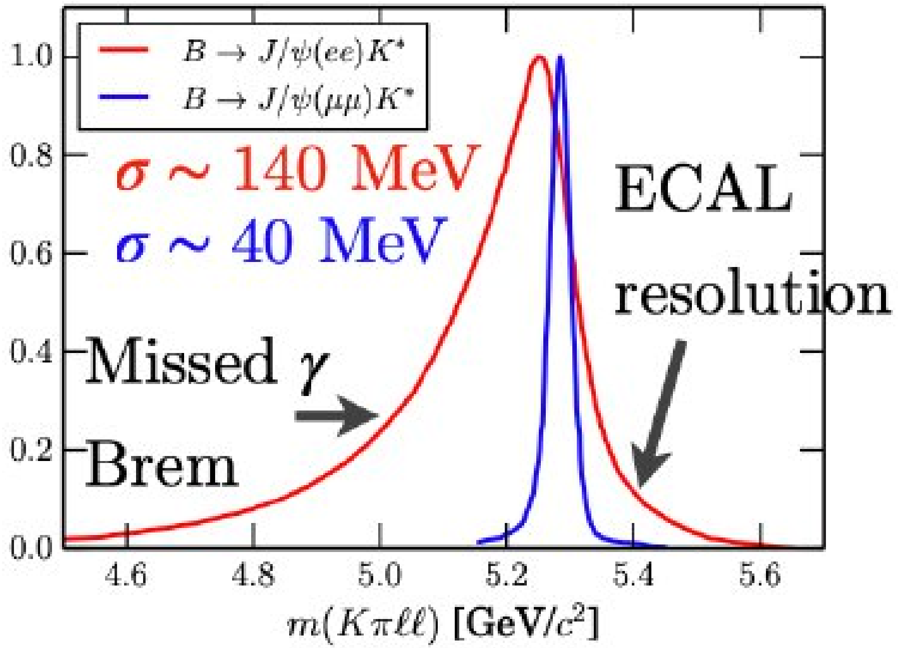
Before the magnet
- electron can be swept out (=lost !)
- kinematics are “wrong”

After the magnet
- not an issue

In both cases E/p is correct

Energy loss ∝ E_e
Energy loss ∝ material

⇒ Use of a recovery algorithm

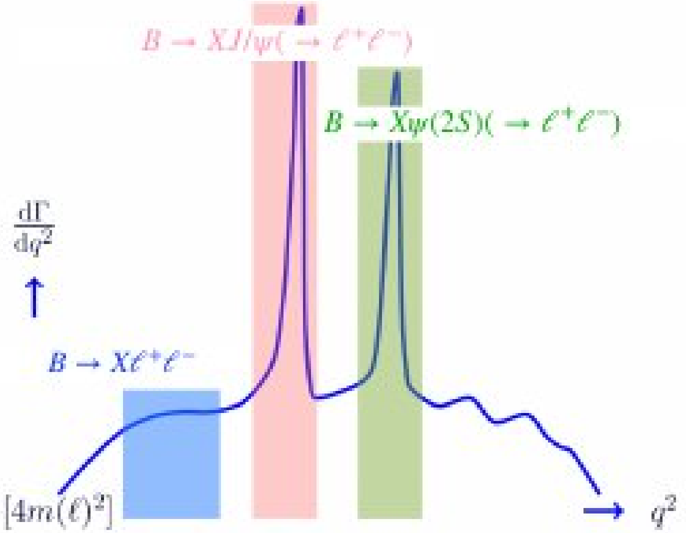


LFU ratio: Experimental strategy

- R_X are measured as double ratios, to mitigate e/μ reconstruction differences

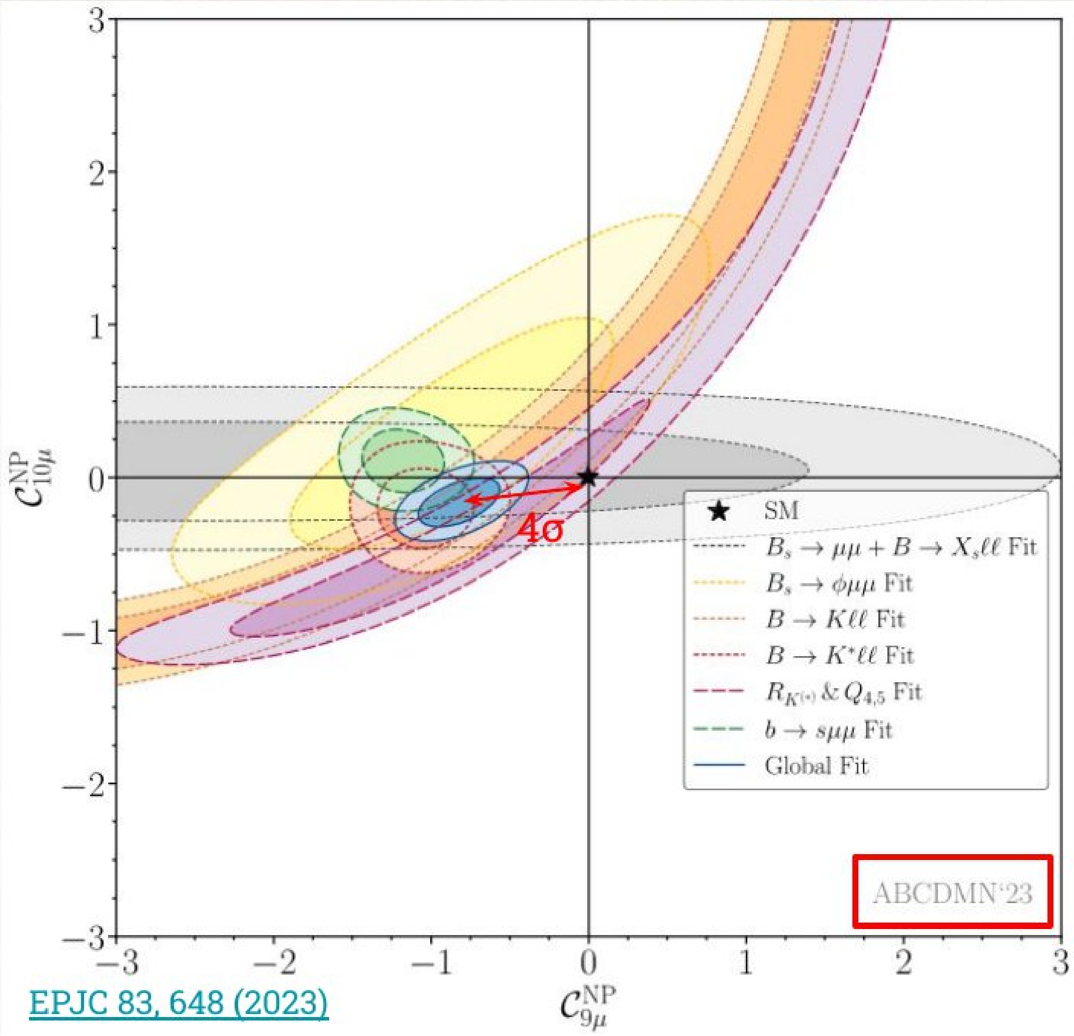
$$R_X = \boxed{\frac{\mathcal{N}_{B\to X\mu^+\mu^-}}{\mathcal{N}_{B\to XJ/\psi(\to\mu^+\mu^-)}} \cdot \frac{\mathcal{N}_{B\to XJ/\psi(\to e^+e^-)}}{\mathcal{N}_{B\to Xe^+e^-}}} \cdot \boxed{\frac{\epsilon_{B\to XJ/\psi(\to\mu^+\mu^-)}}{\epsilon_{B\to X\mu^+\mu^-}} \cdot \frac{\epsilon_{B\to Xe^+e^-}}{\epsilon_{B\to XJ/\psi(\to e^+e^-)}}}$$

- Yields: unbinned maximum-likelihood fits to the B invariant mass
- Efficiencies: simulation corrected for well-known MC/data differences

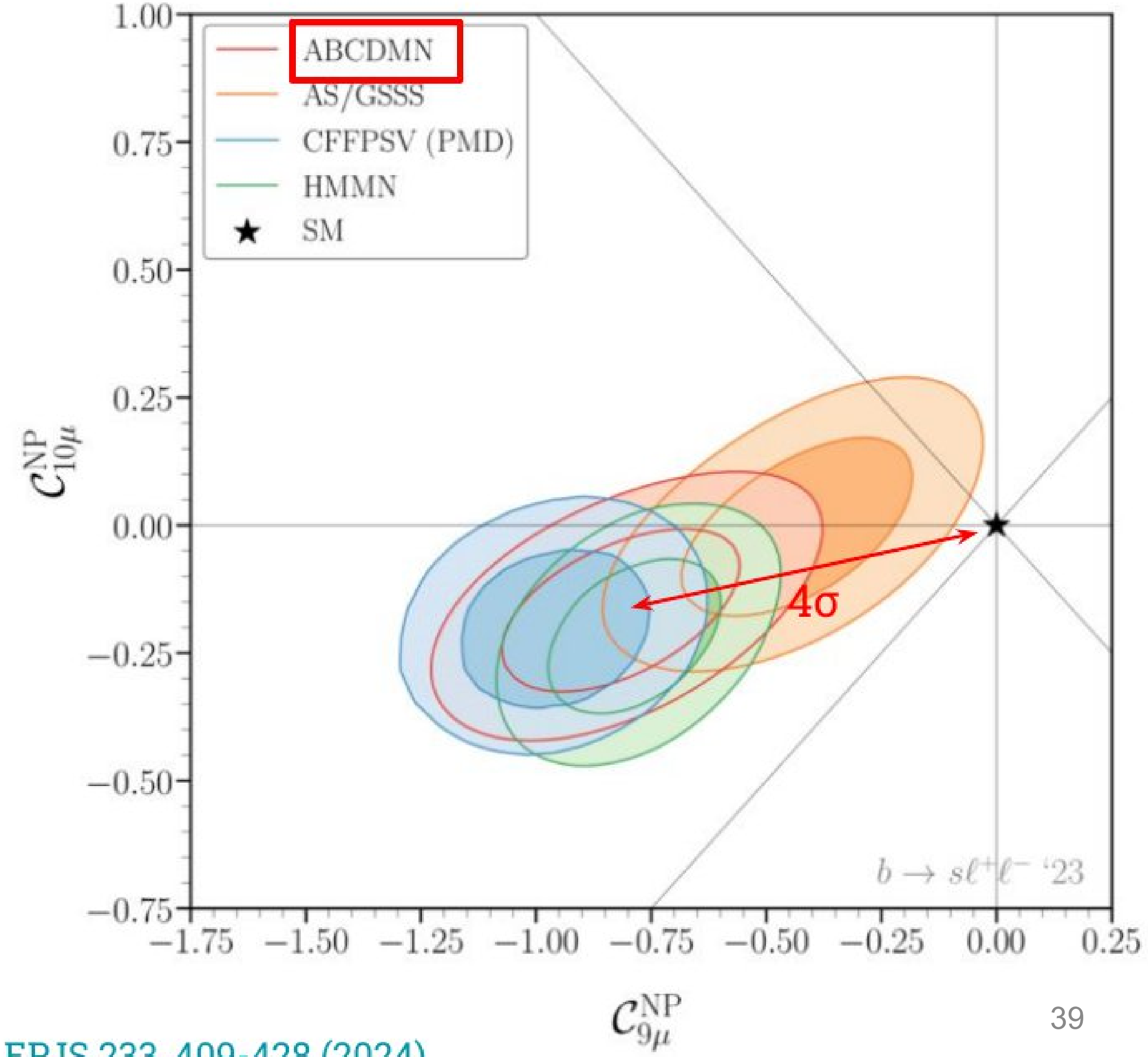


- Resonant channels also used for checks/data driven studies
  - J/ψ and $\psi(2S)$ satisfy LFU, not mediated by $b \to s\ell\ell$
    - $r_{J/\psi} = \dfrac{\mathcal{B}(B \to XJ/\psi(\to \mu\mu))}{\mathcal{B}(B \to XJ/\psi(\to ee))} \equiv 1$ Sensitive to e, μ differences
    - $R_{\psi(2S)} = \dfrac{\mathcal{B}(B \to X(\psi(2S) \to \mu\mu))}{\mathcal{B}(B \to X(J/\psi \to \mu\mu))} \cdot \dfrac{\mathcal{B}(B \to X(J/\psi \to ee))}{\mathcal{B}(B \to X(\psi(2S) \to ee))} \equiv 1$ Efficiency related systematics cancel in double ratio

Wilson Coefficients global fits



EPJC 83, 648 (2023)



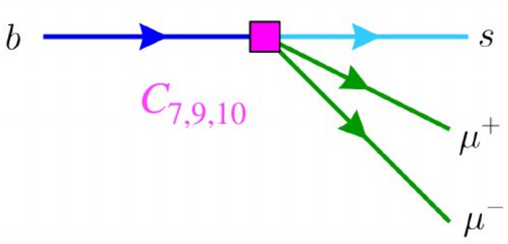
EPJS 233, 409-428 (2024)

LHCb-PAPER-2025-041
In prep.

Legacy Runs1-2 $\mathrm{B}^0 \to \mathrm{K}^{*0}\mu^+\mu^-$ measurement

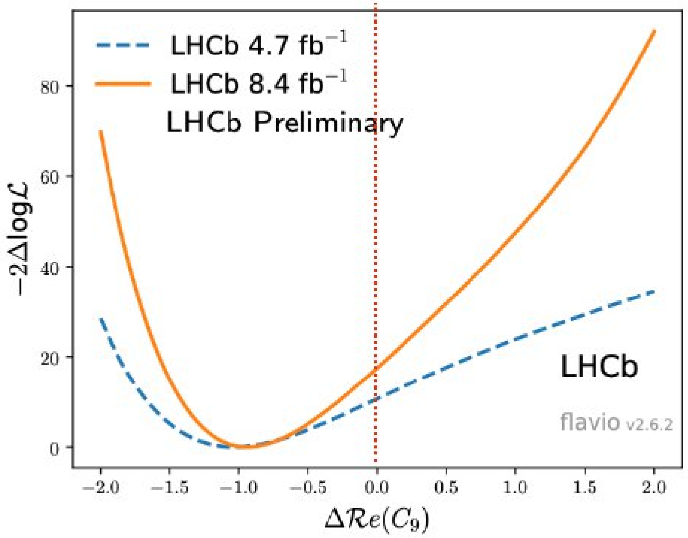
- Two different theory packages are used, which take different approaches, e.g. different non-local form factors

$$H_{eff} \propto \sum_i \mathcal{O}_i C_i$$



C_9 = vector-coupling

$$\Delta Re(C_9) = -0.93^{+0.18}_{-0.16}$$
Significance: 4.1σ



$$\Delta Re(C_9) = -0.94^{+0.22}_{-0.22}$$
Significance: 4.0σ