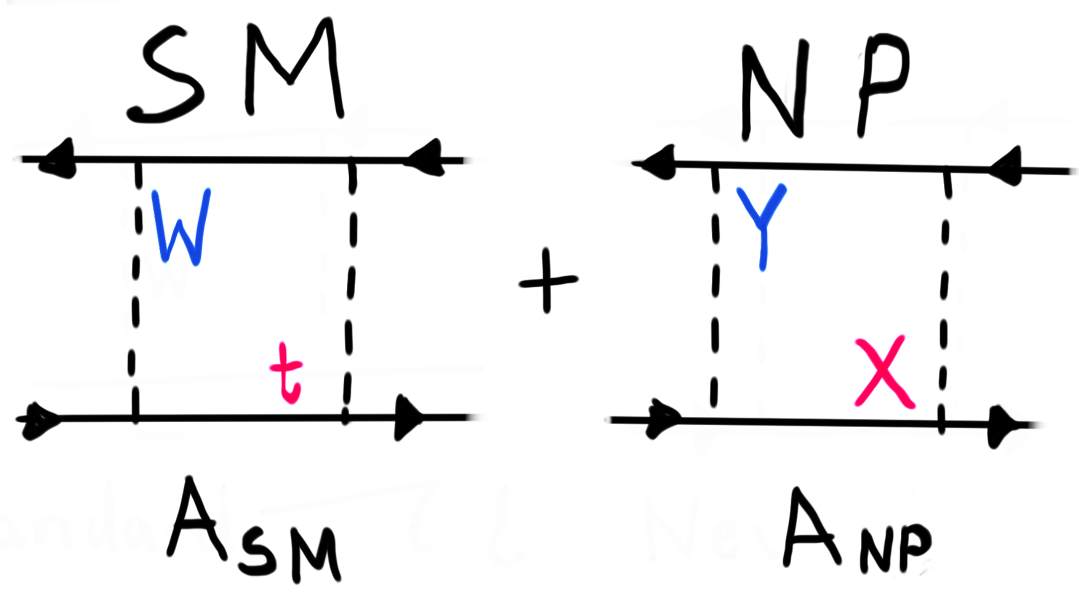
Flavour prospects with the LHCb upgrades

Eva Gersabeck
(on behalf of the LHCb collaboration)

Flavour physics road to new physics



Indirect searches for New Physics

Sensitivity to heavy particles in the loops

Precision measurements test energy scales >100 TeV

✔ Rare processes (suppressed or forbidden in the Standard Model):

e.g. $B_{(s)}^0 \rightarrow \mu\mu$, LFV, CPV in charm….

✔ Observables with very small theoretical uncertainty

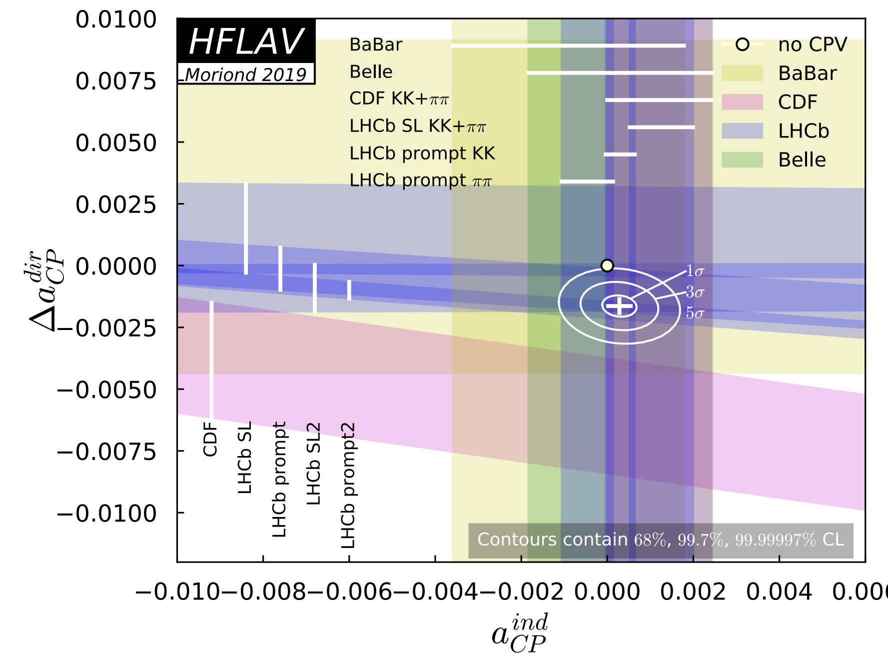
e.g. CKM angle γ, ϕ_s, $\Delta\Gamma_s$…

Experiment ≠ SM predictions ⇒ New Physics

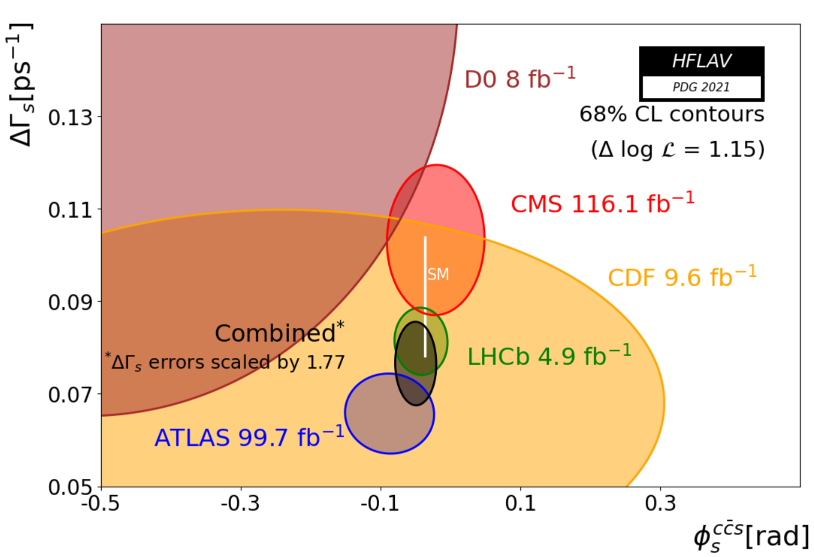
LHCb: a decade of important discoveries and precision measurements

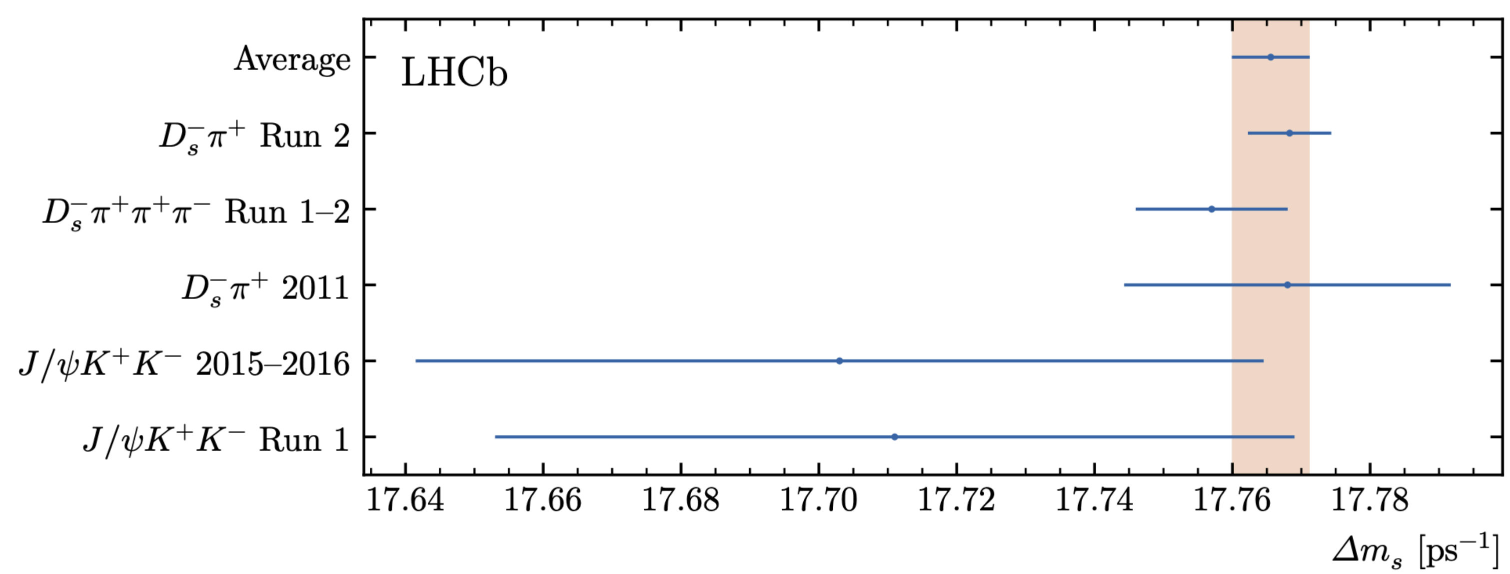
- CPV in D^0 decays and B^+ decays
- Time-dependent CPV in B_s decays
- Flavour anomalies
- Remarkable precision in γ, Δm_s, ϕ_s, A_Γ, $a_{\rm sl}$ etc.
- Precision charm and beauty rare decays
- Doubly charmed baryons, pentaquarks, tetraquarks e.g $T_{\bar{c}c\bar{c}c}$

Talks by N. Watson, T. Pajero, Zh. Wang

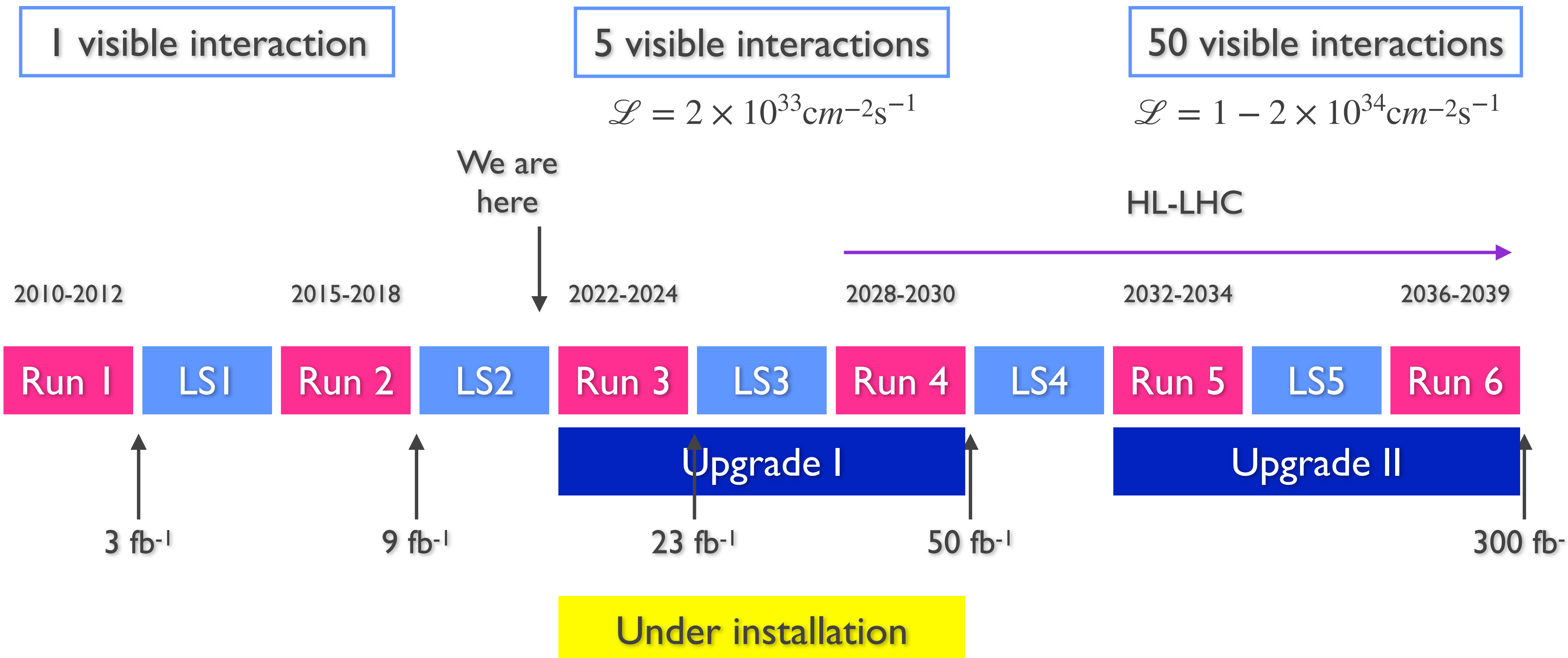


arXiv:2104.04421, on arXiv as of today, submitted to Nature Physics



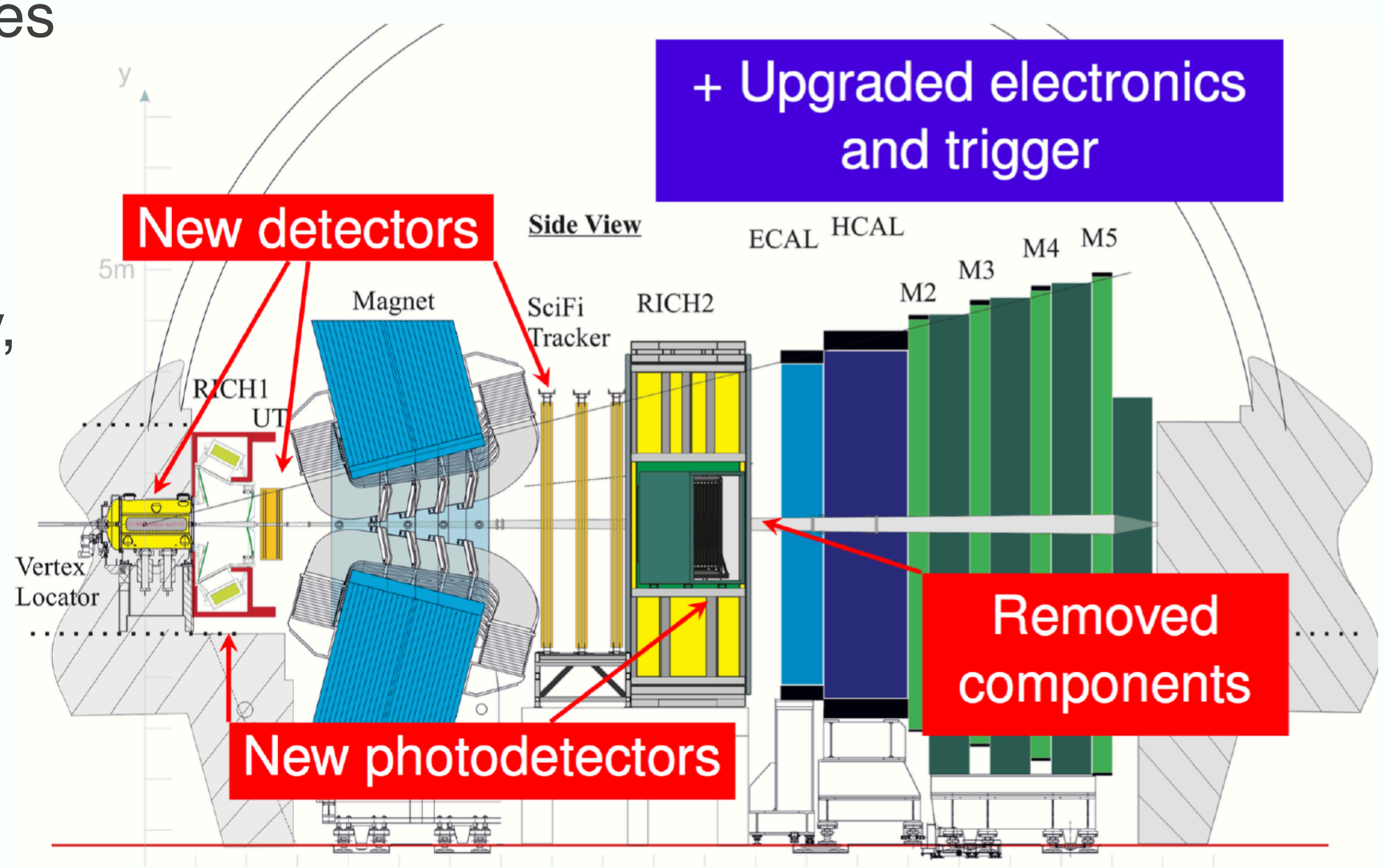


Timeline for the LHCb upgrades



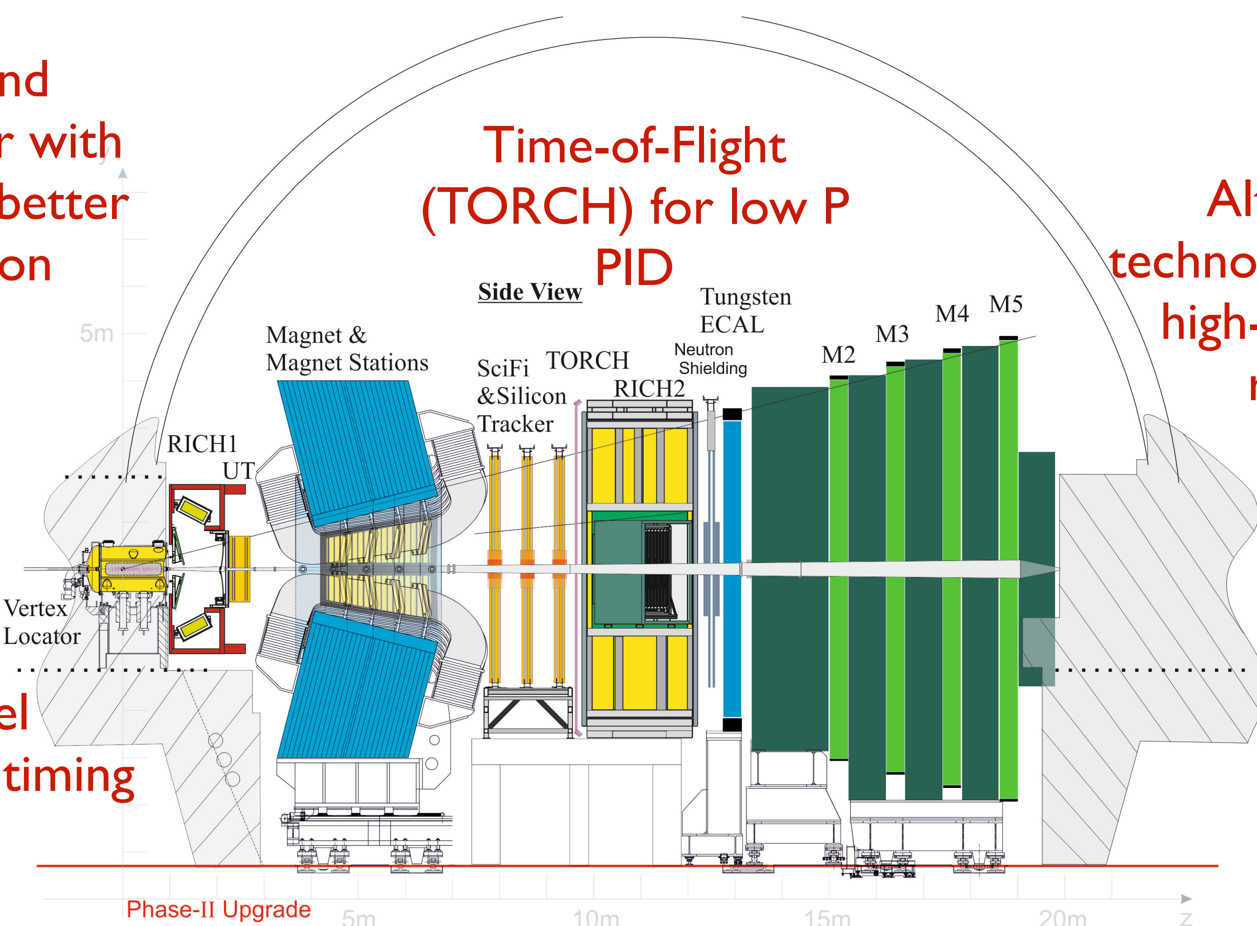
The LHCb upgrade I

- **LHCb upgrade I: 50 fb^{-1}** in Runs-3,4 (2022-2024, 2027-2030).
- Strategy & challenges
  - Instantaneous Luminosity $\mathscr{L}$ increasing by factor 5 up to 2x10^{33}cm^{-2}s^{-1}
  - Increase readout rate to 40 MHz
  - Remove L0 hardware trigger
  - Full software trigger with first stage on GPUs
    - Huge boost to signal efficiencies
- Higher pile-up, occupancy and radiation levels
  - New detectors: higher granularity, radiation hardness,…
  - New front end electronics



The LHCb upgrade II

- **LHCb upgrade II**: **300 fb^{-1}** in Runs-5,6 (2032-2034, 2036→).
- Run at a 10x higher luminosity: major challenge
  - Retain the performance under much harsher conditions
  - Requirements: ~50 ps timing (VELO), radiation hardness, & high granularity
- Extensive R&D underway (hardware and software)



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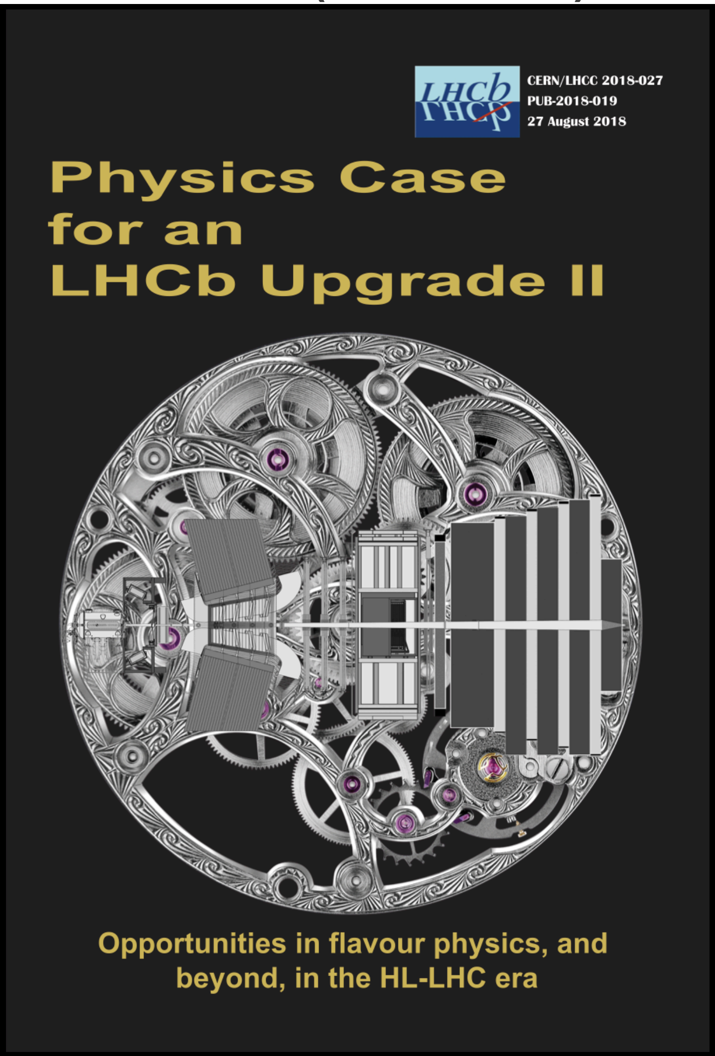
[LHCB-PUB-2018-009] arXiV:1808.08865

Strong flavour physics case but also covering EW physics, dark sector, spectroscopy, heavy ions, fixed-target mode (SMOG) etc.



- projections assume similar or better performance
- trigger efficiencies are expected to be higher but will vary from channel to channel

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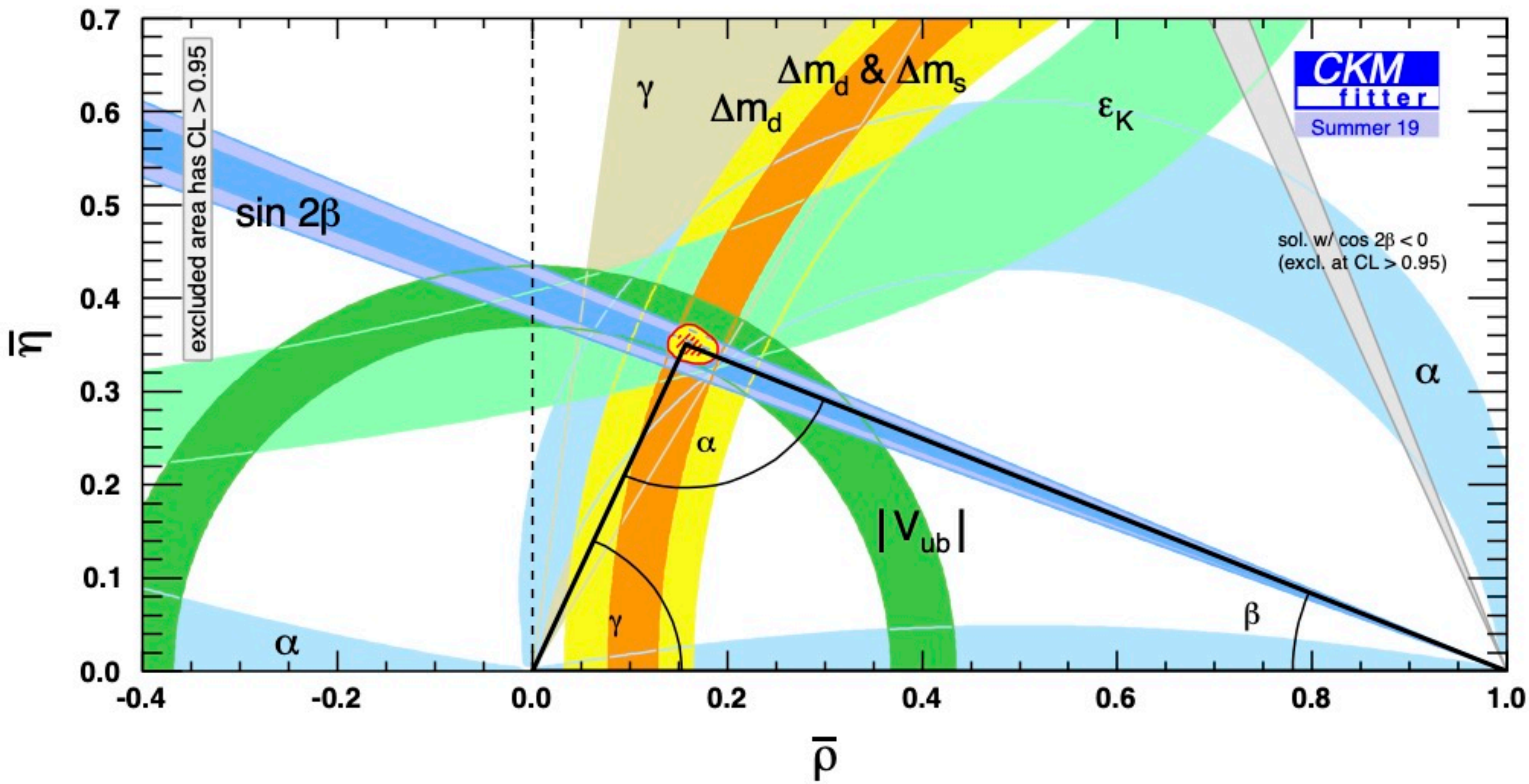
Mixing and CP violation

The CKM angle γ



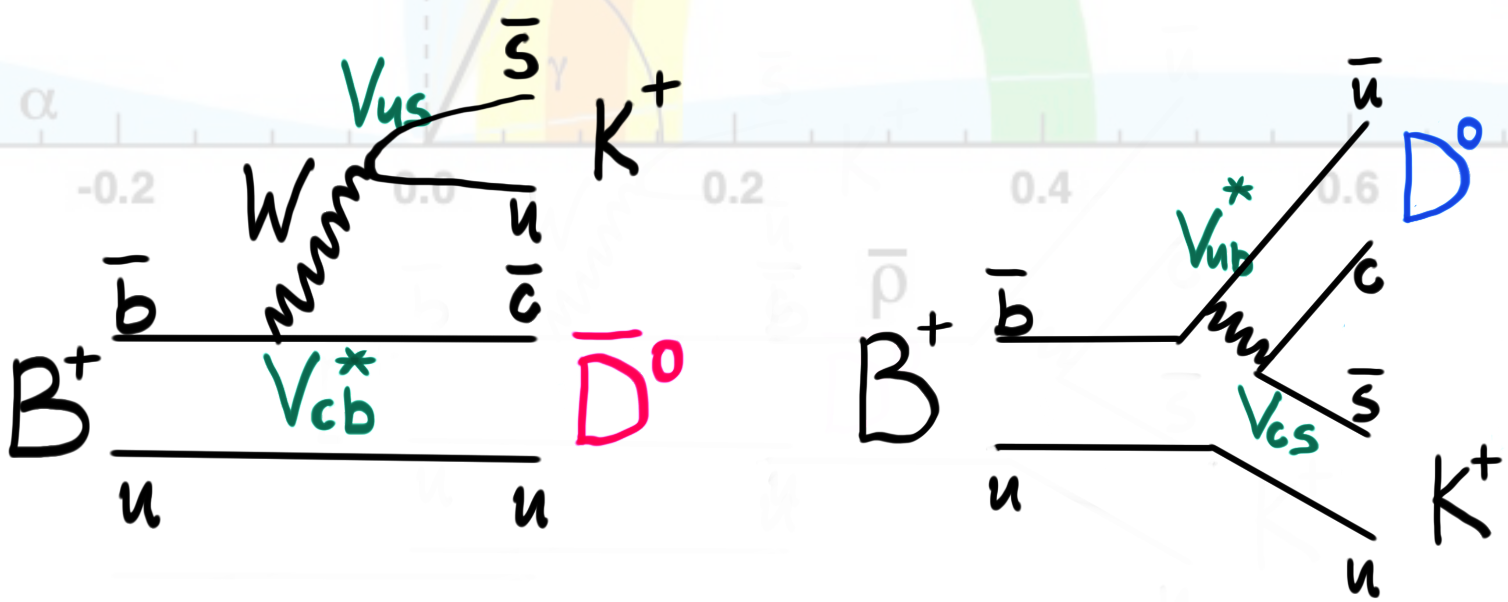
Triangle over-constrained by several different measurements

Why γ?

- SM benchmark: sensitive to New Physics effects
- Theory uncertainty on γ is very small $\delta\gamma/\gamma \approx O(10^{-7})$ *Zupan and Brod'13 JHEP 1401 (2014) 051*
- γ can probe for new physics at extremely high-energy scales $\sim O(10^2\text{-}10^3)$ TeV *Zupan, arXiv:1101.0134*
- NP can lead to a sizeable 10° effect *Lenz, Tetlalmatzi-Xolocotzi, JHEP07(2020)177*
- Overconstraining the CKM triangle central to testing the SM description of CPV

only CKM angle accessible at tree level ($b \to u$ and $b \to c$ transitions in $B \to DK$ decays)

$$\gamma = \arg\left[-\frac{V_{ub}^* V_{ud}}{V_{cb}^* V_{cd}}\right]$$



Upgrade sensitivity to γ

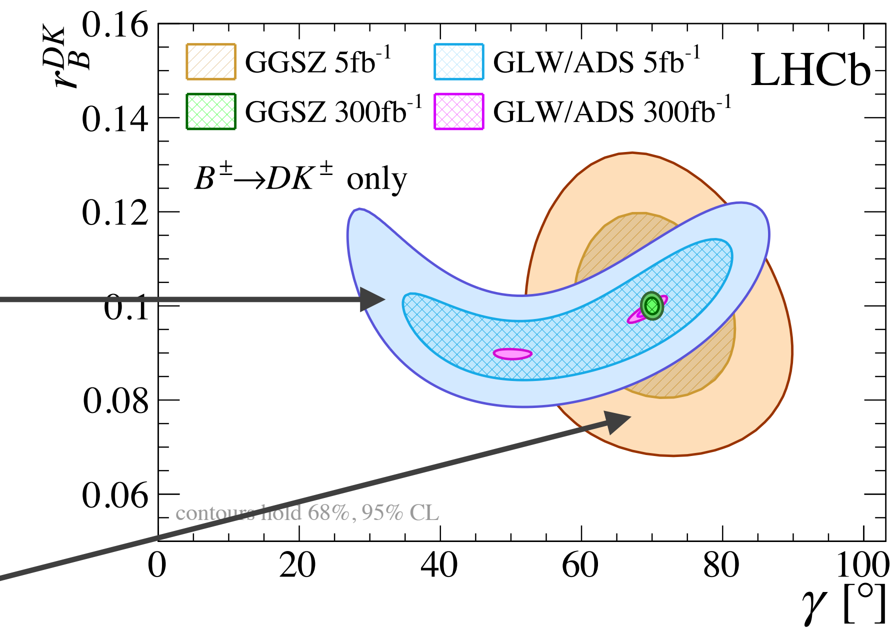
LHCb average: $\gamma = \left(65.4^{+3.8}_{-4.2}\right)^\circ$

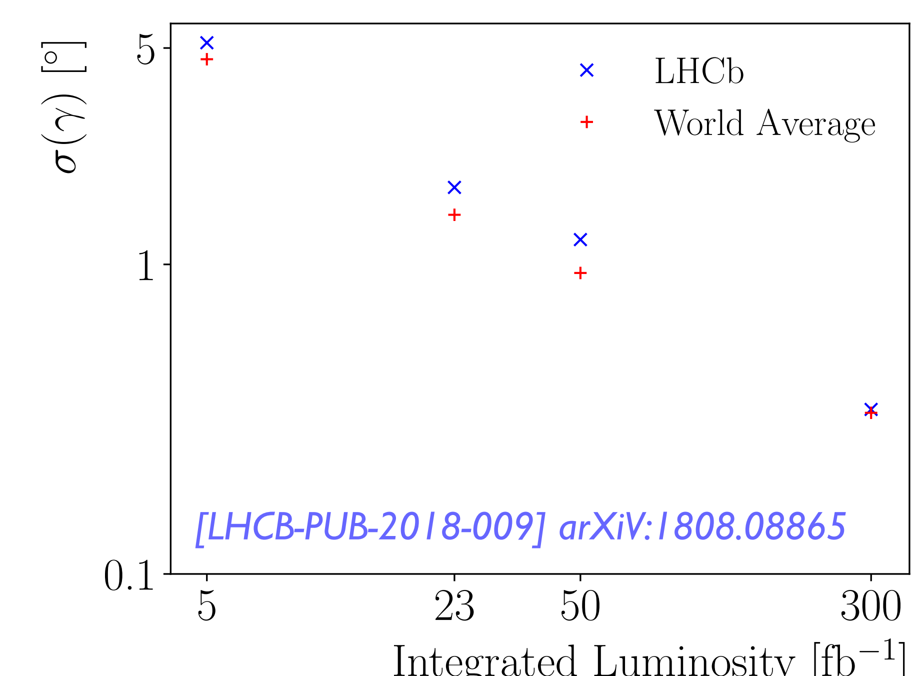
Gamma Combo LHCb-CONF-2021-001

Indirect measurements: $\gamma = \left(65.7^{+0.9}_{-2.7}\right)^\circ$

CKM fitter'19

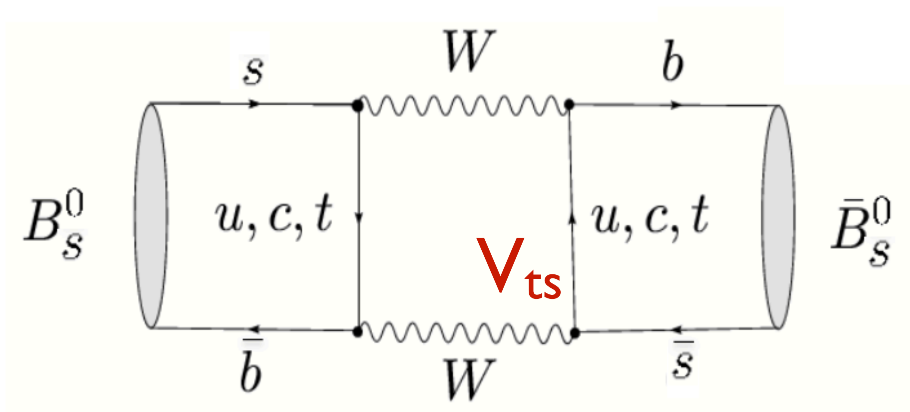
- For the ultimate precision, we combine many final states $B \to D^{(*)}h^{(*)}$
    - charged, neutral
    - two- and multi body D decays
    - fully or partially reconstructed
- GLW/ ADS method: Several final states $D \to KK$, $D \to \pi\pi$, $D \to K\pi$, $D \to \pi K$
    - 30 CP observables, strong constraints on γ
- BPGGSZ method with $D \to K^0_s\pi^+\pi^-$ and $D \to K^0_s K^+K^-$
    - Compare B^+ and B^- yields in Dalitz plot bins
    - Most precise single measurement!
    - Requires input for the strong phase from BESIII
- Expect ~1° for individual modes, ~0.35° combined sensitivity

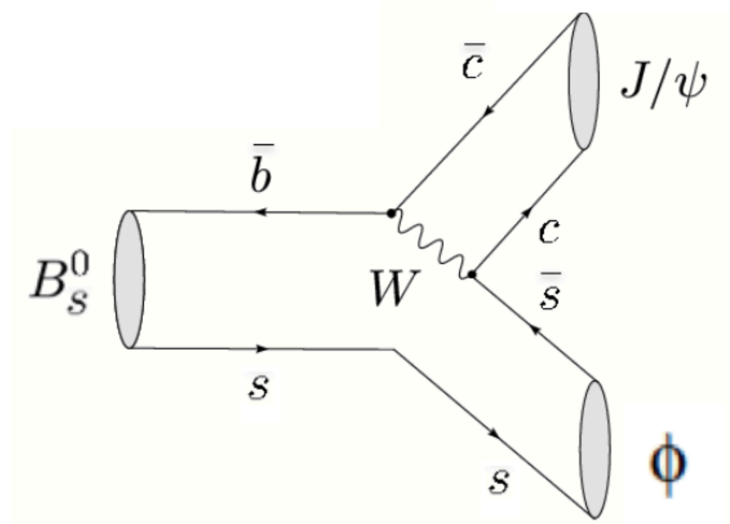


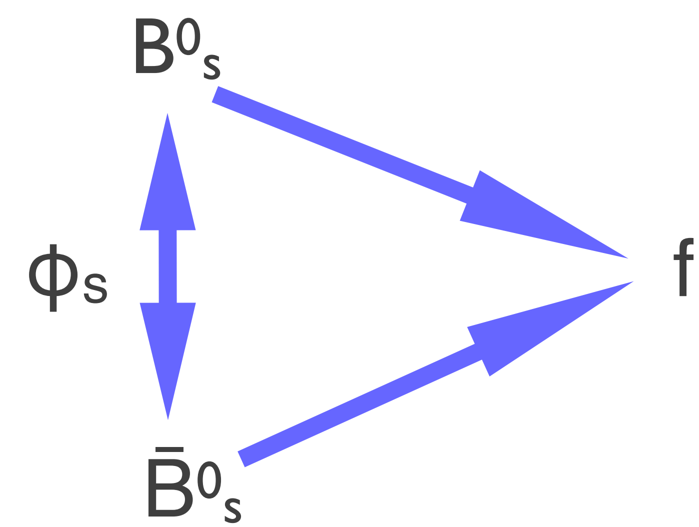


Measurements of ϕ_s

- CKM angle β_s: $\phi_s = -2\beta_s = -2\arg(-V_{cs}V_{cb}^{*}/V_{ts}V_{tb}^{*})$







Golden channel: $B^0_s \rightarrow J/\psi\phi \rightarrow \mu^+\mu^-K^+K^-$:
proceeds (mostly) via a $b \rightarrow c\bar{c}s$ tree diagram

- Interference between Bs mixing and decay graphs
- Measures the phase-difference ϕ_s between the two diagrams
- Small pollution of sub-leading SM amplitudes that must be controlled via additional measurements

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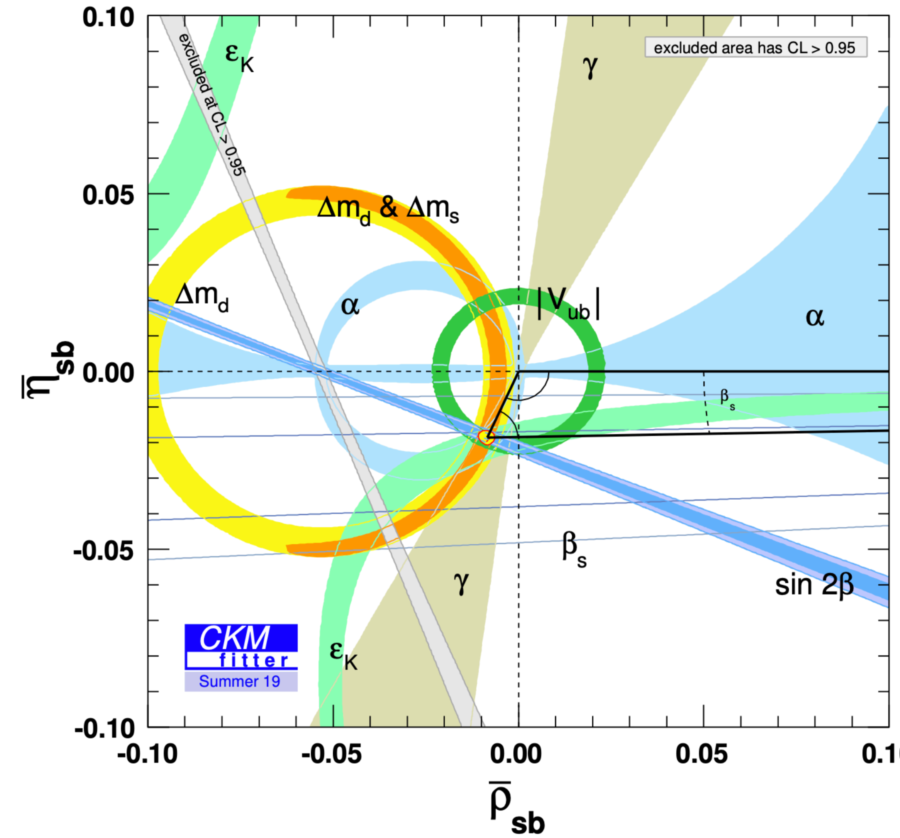
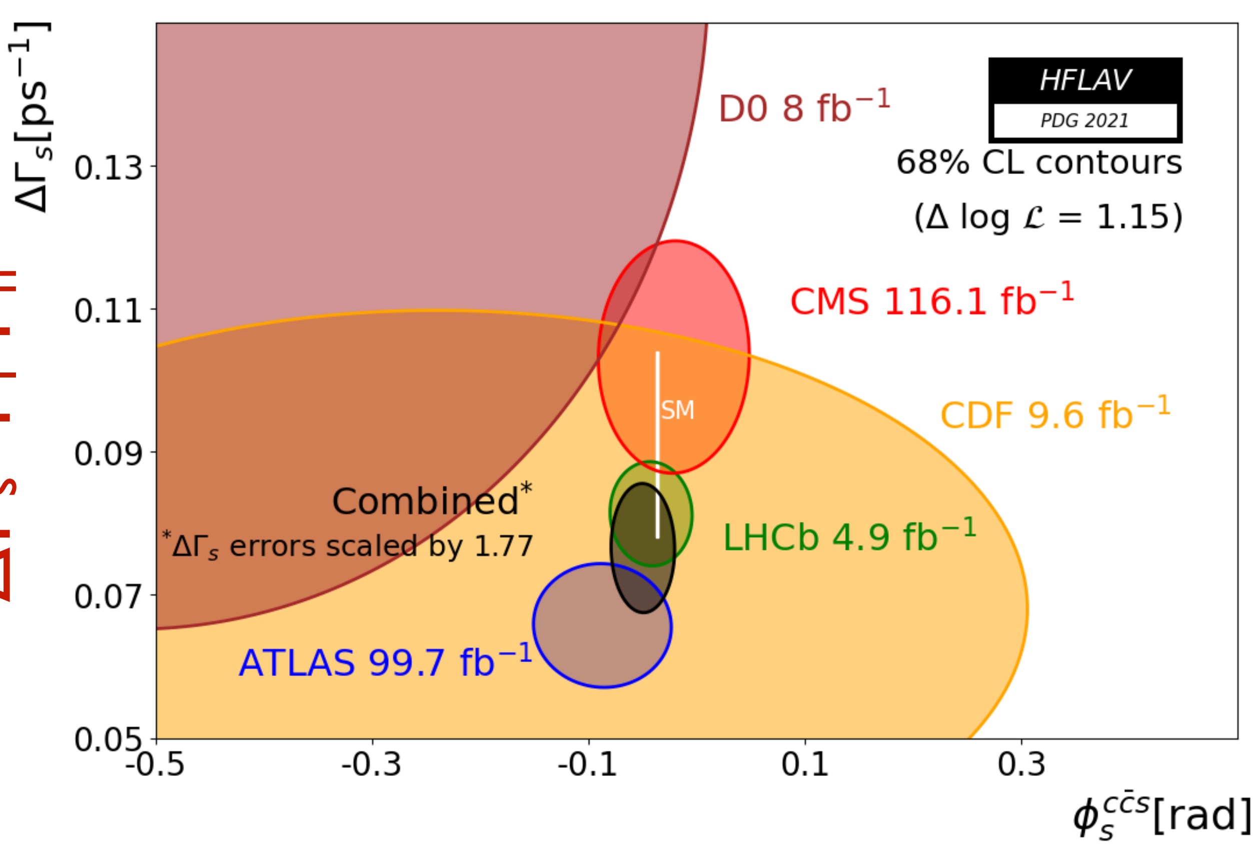
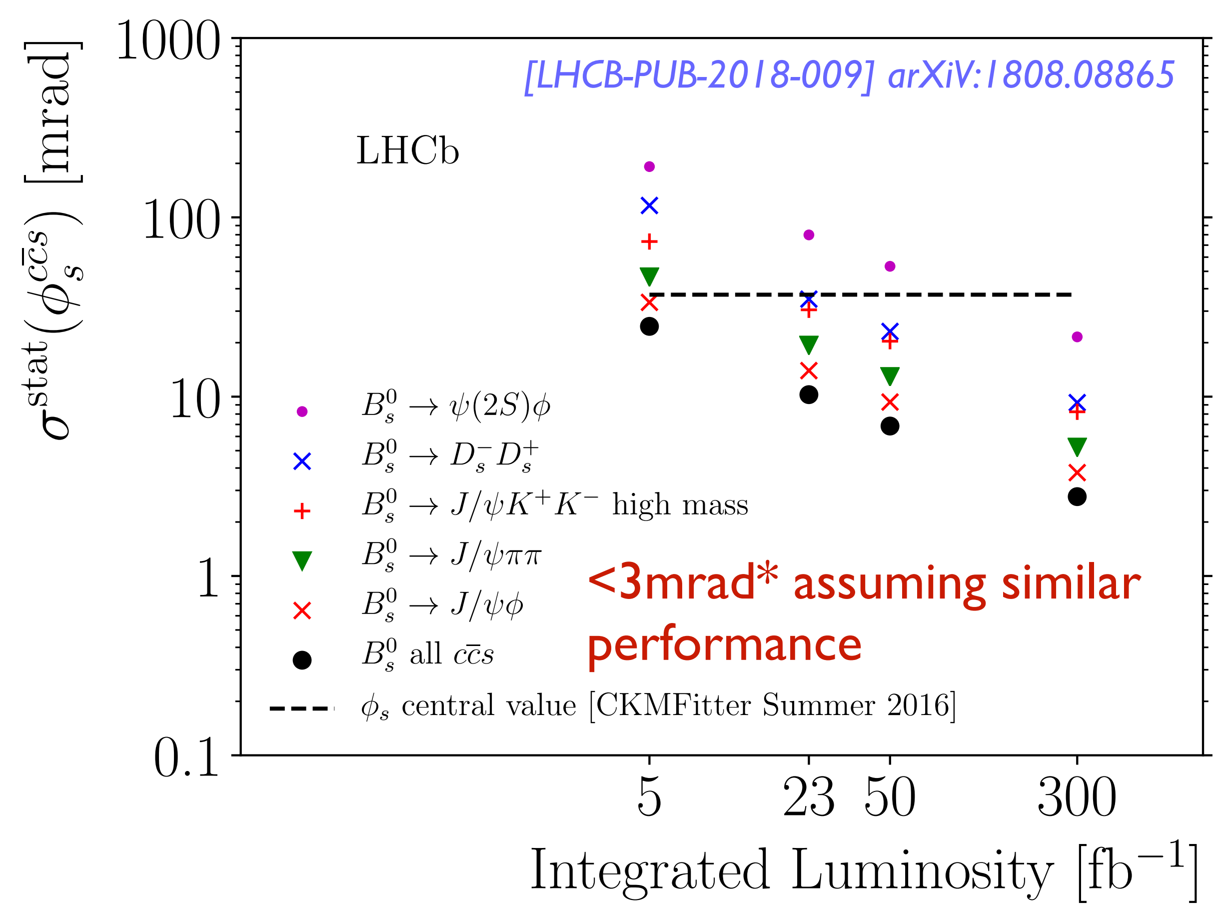
Current status of ϕ_s and projections

- $\phi_s = -2\beta_s = -2\arg(-V_{cs}V_{cb}^*/V_{ts}V_{tb}^*)$
- Tiny SM prediction: $\phi_s = -36.5 \pm 1.3$ mrad
  CKMFitter Phys. Rev. D 91 (2015) 073007
  - can be altered by new physics
- Global fit HFLAV $\phi_s = -41 \pm 25$ mrad



$\Delta\Gamma_s = \Gamma_l - \Gamma_h$





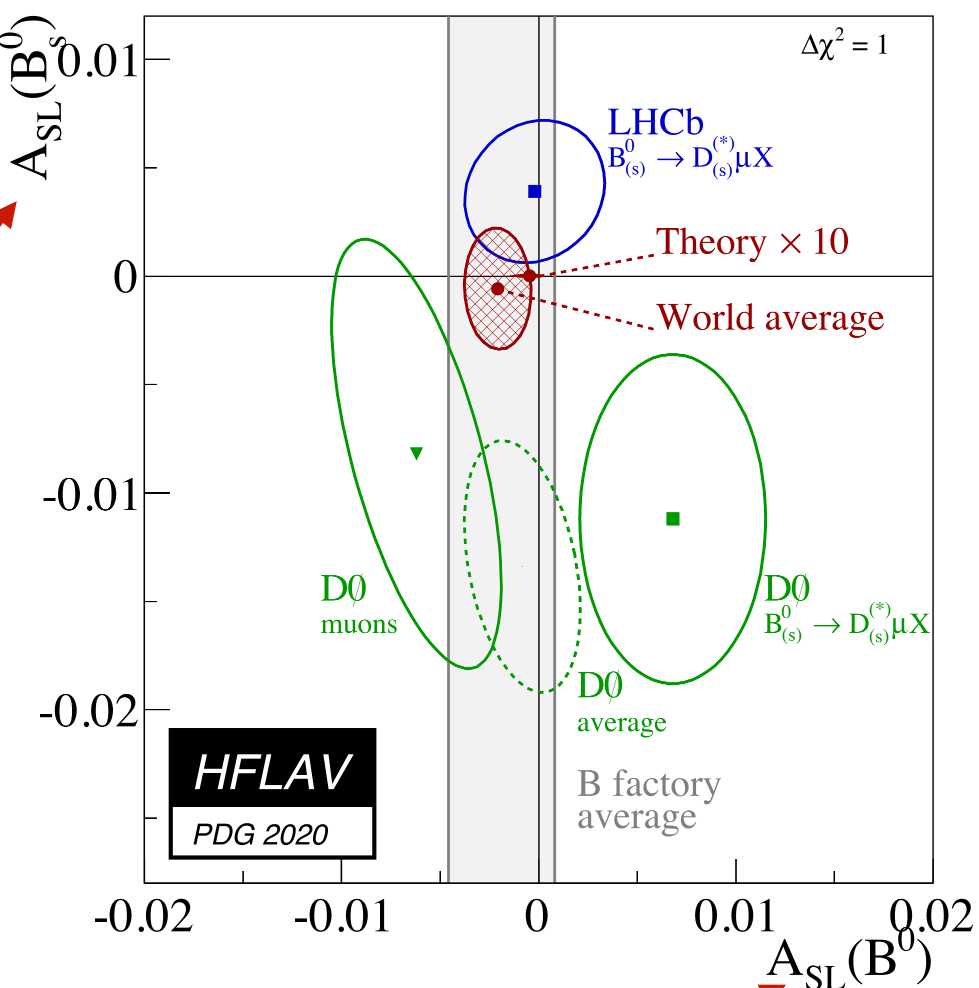
CP violation in neutral B mesons

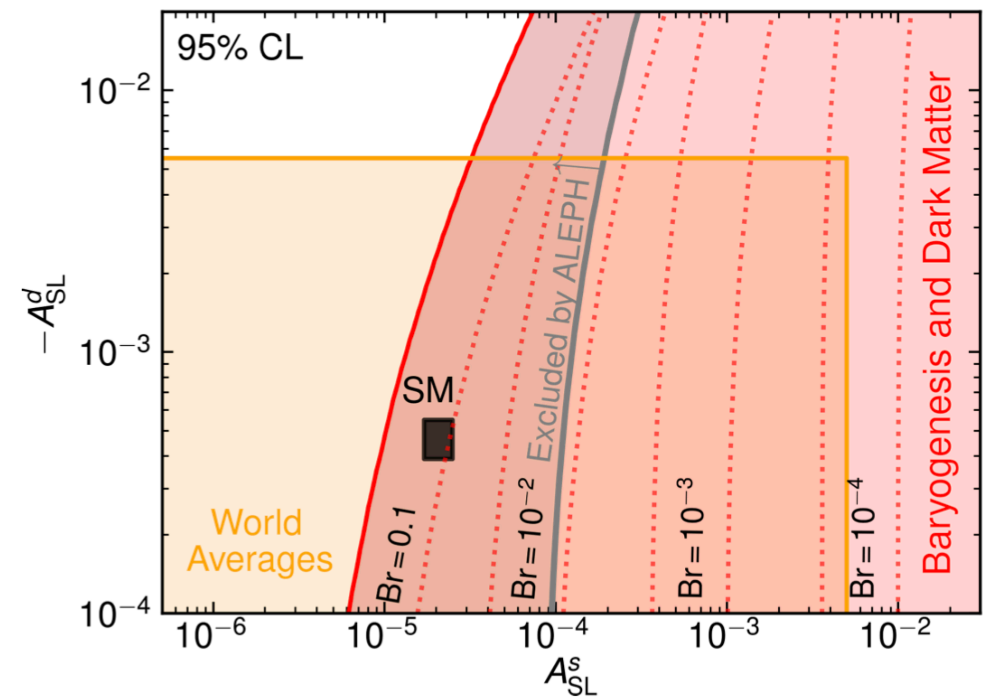
- The CP asymmetries in neutral B decays $B^0_{(s)} \to D^{(*)}_{(s)}\mu\nu_\mu X$

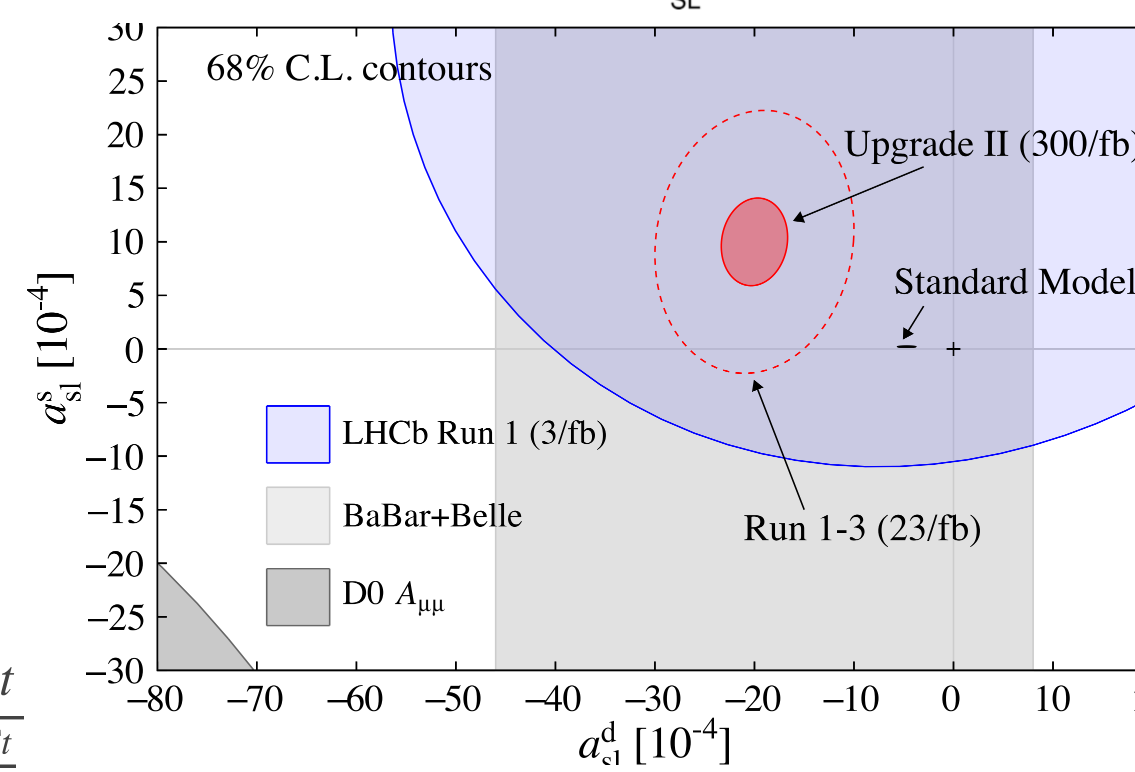
arXiv: 2101.02706

$$a_{SL} = \frac{\Gamma\left(\bar{B}^0(t) \to B^0(t) \to f\right) - \Gamma\left(B^0(t) \to \bar{B}^0(t) \to \bar{f}\right)}{\Gamma\left(\bar{B}^0(t) \to B^0(t) \to f\right) + \Gamma\left(B^0(t) \to \bar{B}^0(t) \to \bar{f}\right)}$$

$$A_{meas} = \frac{\Gamma(f) - \Gamma(\bar{f})}{\Gamma(f) + \Gamma(\bar{f})} = \frac{a^s_{SL}}{2} + A_D$$







[LHCB-PUB-2018-009] arXiV:1808.08865

$$A_{meas} = \frac{\Gamma(f,t) - \Gamma(\bar{f},t)}{\Gamma(f,t) + \Gamma(\bar{f},t)} = \frac{a^d_{SL}}{2} + A_D - \left(A_P + \frac{a^d_{SL}}{2}\right)\frac{\cos \Delta m t}{\cosh \frac{\Delta\Gamma t}{2}}$$

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Mixing and CP violation in charm decays

CP violation in charm

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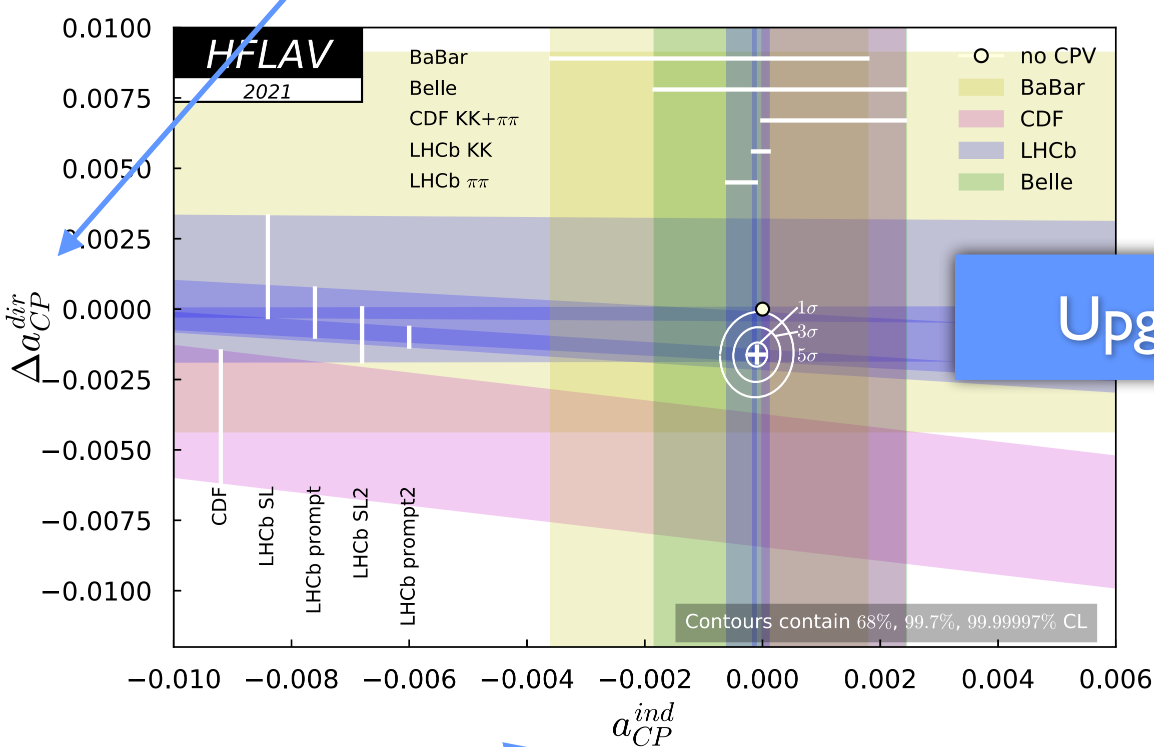
LHCb, Phys. Rev. Lett. 122 (2019) 211803

- Charm CP violation in decay discovered in 2019 $\Delta A_{CP} = [-15.4 \pm 2.9] \times 10^{-4}$

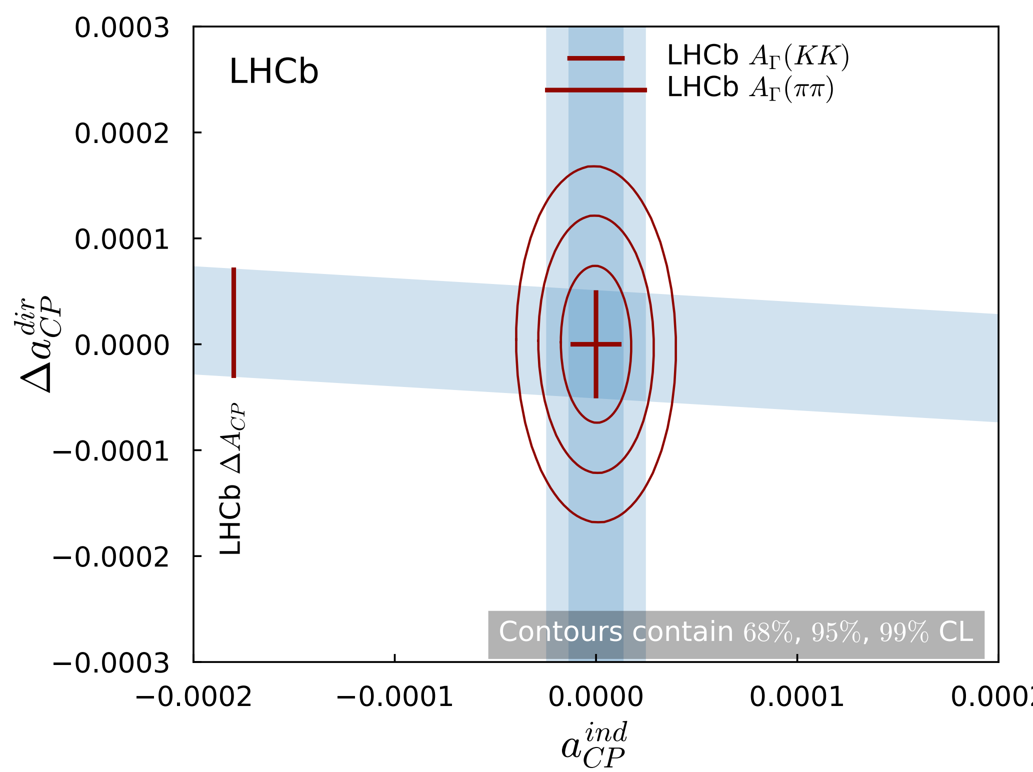
$$\Delta A_{CP} \equiv A_{CP}(K^-K^+) - A_{CP}(\pi^-\pi^+) \approx \Delta a_{CP}^{\rm dir}\left(1 + \frac{\overline{\langle t \rangle}}{\tau} y_{CP}\right) + \frac{\Delta \langle t \rangle}{\tau} a_{CP}^{\rm ind}$$

SM or BSM?: open question

Need more measurements in related decays e.g. $D^0 \to K_S^0 K_S^0$ (0.28%), $D^0 \to K_S^0 \bar{K}^{*0}$ (0.6×10^{-4}), $D^0 \to K_S^0 K^{*0}$ (0.6×10^{-4}), $D_s^0 \to K_S^0 \pi (3.2 \times 10^{-4})$. etc.



Upgrade II



[LHCB-PUB-2018-009] arXiV:1808.08865

$$A_\Gamma = -a_{CP}^{ind} = \eta_{CP}\left[\frac{1}{2}(A_M + A_d) y \cos\phi + x \sin\phi\right] = \frac{\tau(\bar{D}^0 \to h^+h^-) - \tau(D^0 \to h^+h^-)}{\tau(\bar{D}^0 \to h^+h^-) + \tau(D^0 \to h^+h^-)}$$

No sign of indirect CPV yet SM expectation 1 order of magnitude lower: need the full Upgrade II statistics to explore the parameters space
Great potential for multi body decays e.g. $D^0 \to K3\pi$

CP violation in charm

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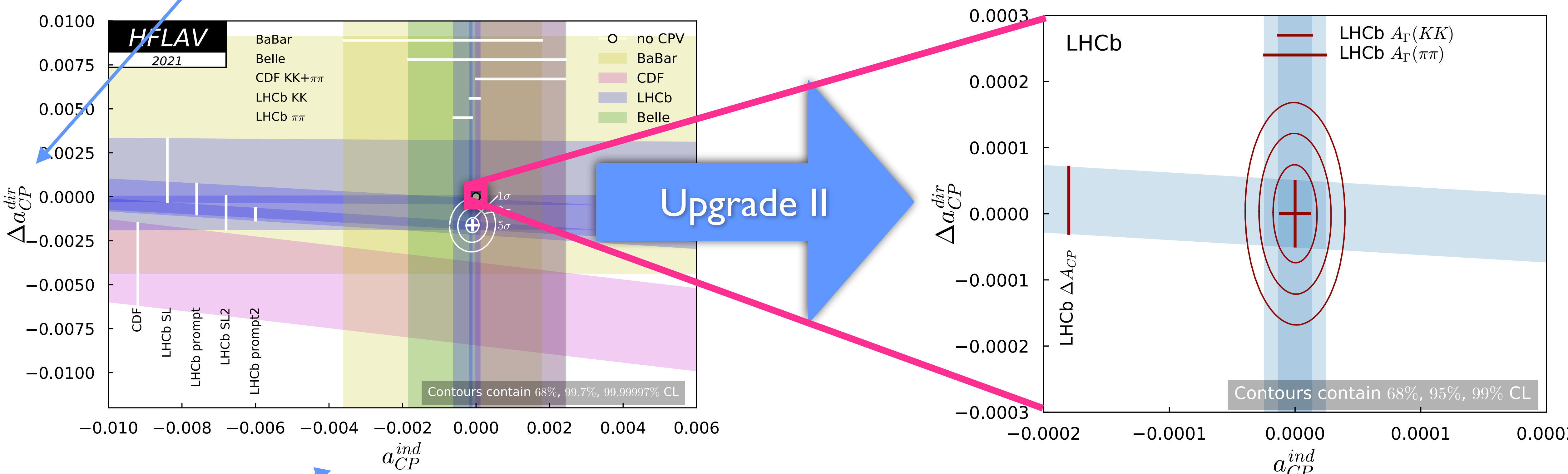

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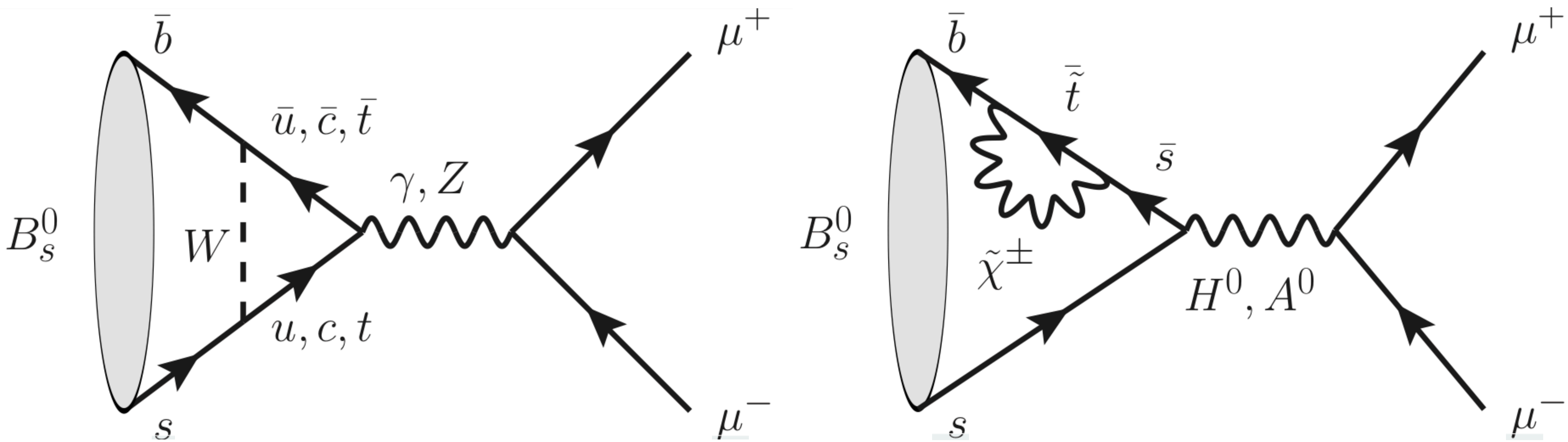
Rare decays and LFU

FCNC in beauty decays: $B_{(s)}^0 \to \mu\mu$ decay



- $B_{(s)}^0 \to \mu\mu$ is suppressed in the SM: very sensitive to NP due to virtual contributions
- Different coupling structure due to NP contributions?

LHCb result on $B^0_{(s)} \to \mu\mu$

ARXIV:2108.09284 (submitted to PRL), ARXIV:2108.09283 (submitted to PRD)

- Full Run 1+2 data, 9 fb^{-1}
  - Update result with improved selection and background suppression

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = \left(3.09^{+0.46+0.15}_{-0.43-0.11}\right) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 2.6 \times 10^{-10}\ [95\ \%\ \text{CL}]$$

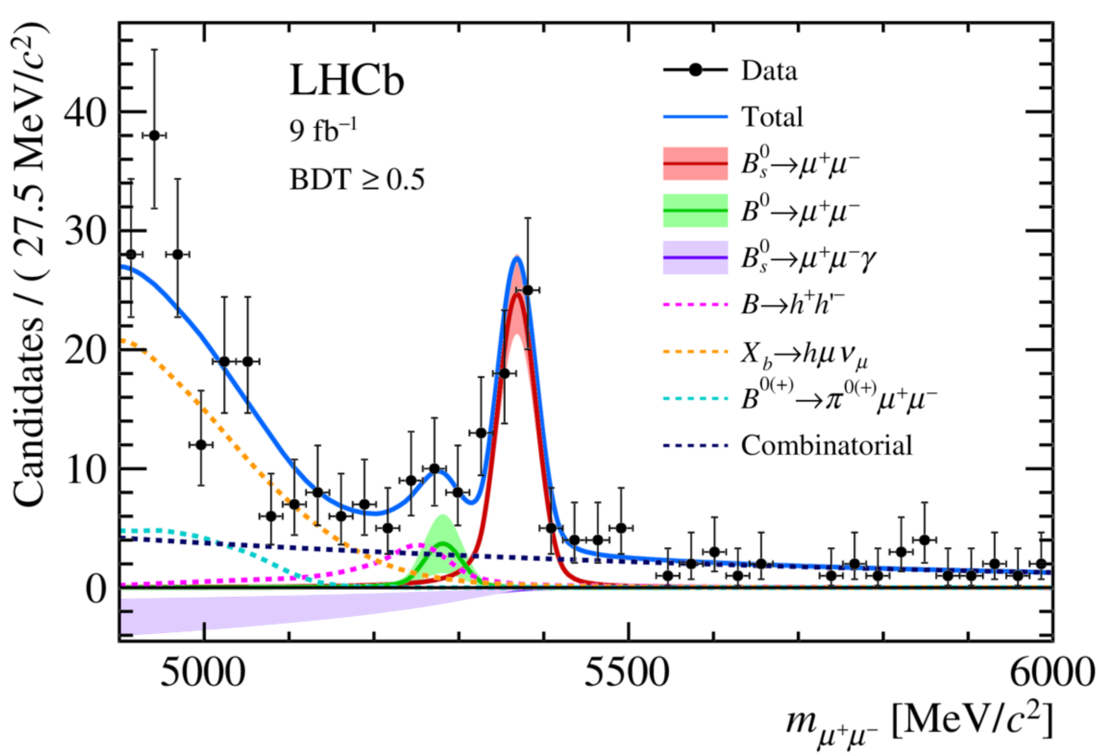
  - Improved measurement of the $B^0_s \to \mu\mu$ effective lifetime, 2.07 ± 0.29 ± 0.03 ps

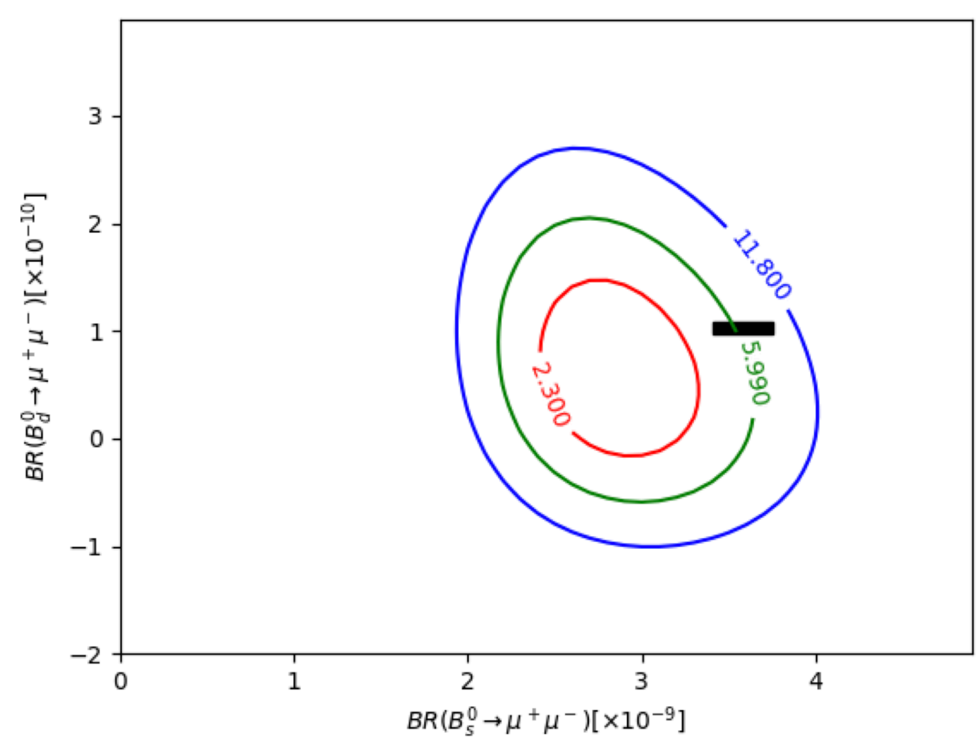
LHCb projections depend on assumptions of the systematic uncertainty

23 fb^{-1}	300 fb^{-1}
±0.30×10^{-9}	±0.16×10^{-9}
34%	10%
±0.15	±0.04

[LHCB-PUB-2018-009] arXiV:1808.08865

Result compatible with SM expectation (~2σ away when using a combined LHCb, ATLAS, CMS result arXiv:2104.10058)





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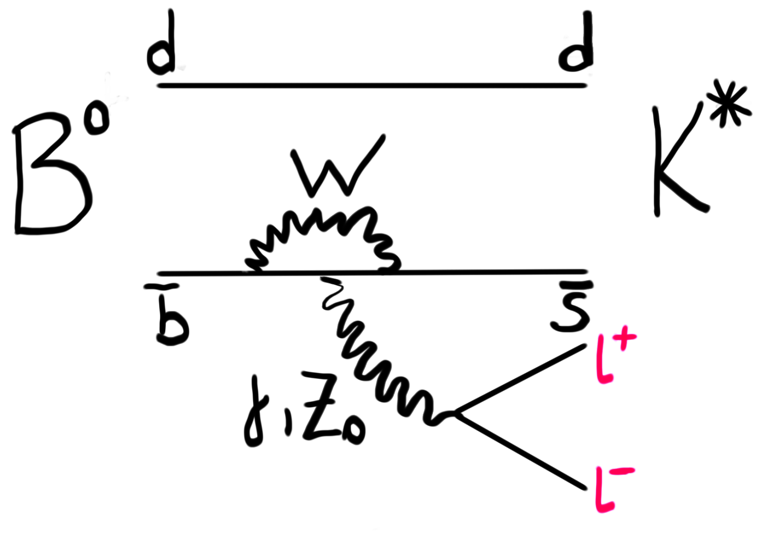
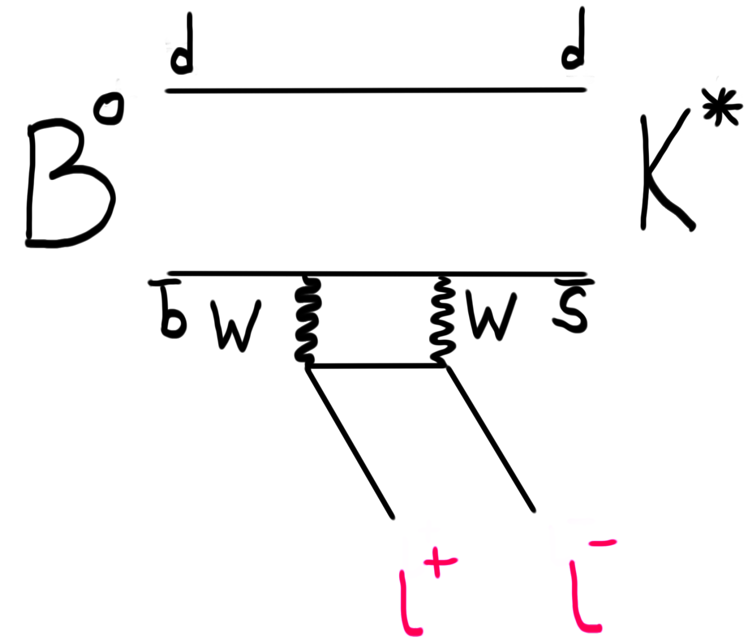
b→sll transitions





- $B^0 \to K^{*0} \mu\mu$ is one of the LHCb golden channels
- Several sensitive observables: q^2 distribution, forward-backward asymmetries, angular observables
- Right choice of observable can reduce the hadronic uncertainties: P'_5 *[S. Descotes-Genon et al., JHEP, 05 (2013) 137]*

Upgrade projections

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FCNC processes are described by the effective Hamiltonian
New heavy particles can significantly contribute, affecting decay rates and angular distributions

Local Operator (effective vertex)

NP coupling

$$\mathcal{H}_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^{*} \sum \mathcal{C}_i \mathcal{O}_i + \frac{k}{\Lambda_{NP}^2} \mathcal{O}_{NP}$$

Willson Coefficient (effective coupling)

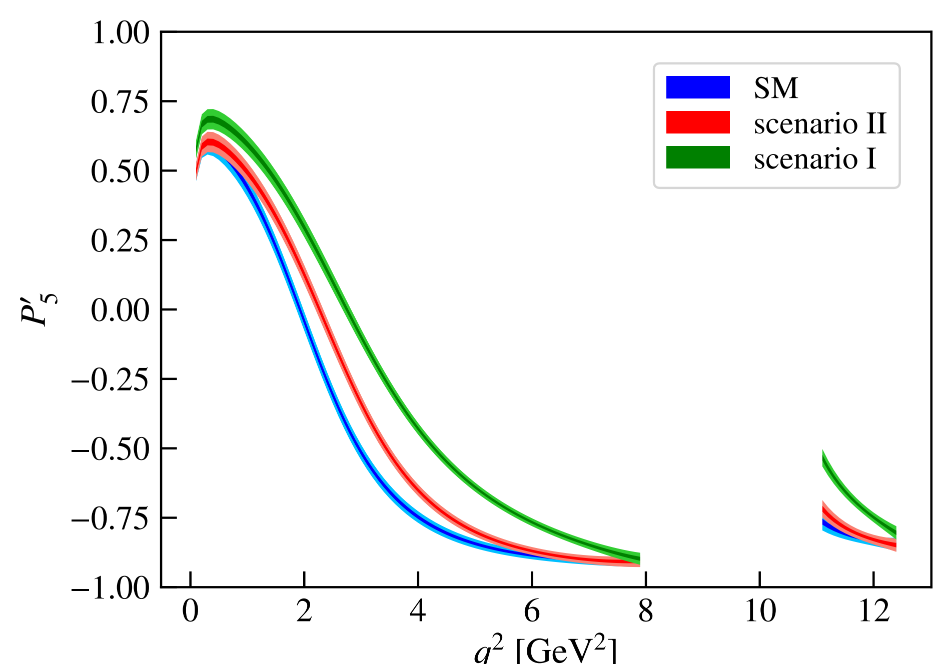
i=9, 10 correspond to the coupling to a vector and an axial-vector leptonic current

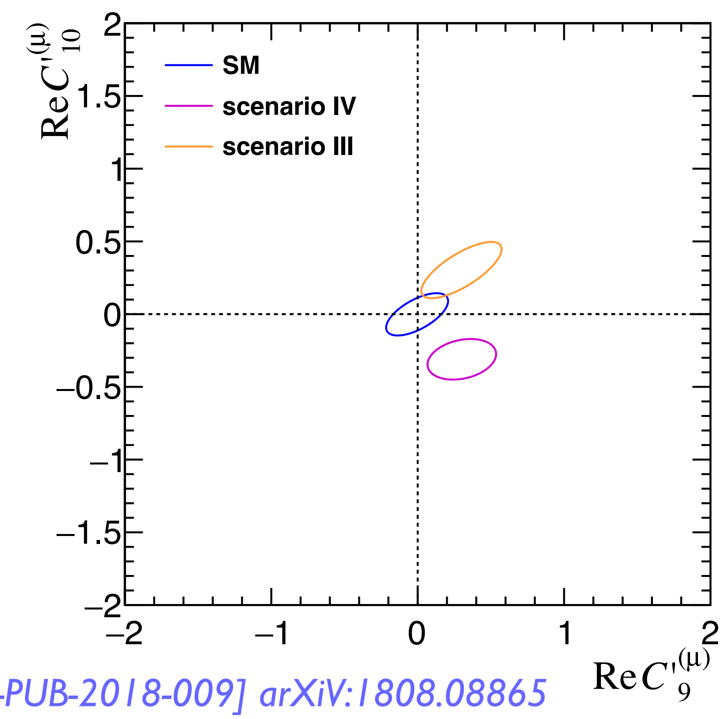
NP scale

with about 400k $B^0 \to K^{*0}\mu^+\mu^-$ decays in Upgrade II

Scenario I: best explains $b \to s\ell\ell$
Scenario II: $b \to s\ell\ell$ & $b \to c\ell\nu_\ell$
Scenarios III and IV: small contribution from right-handed currents

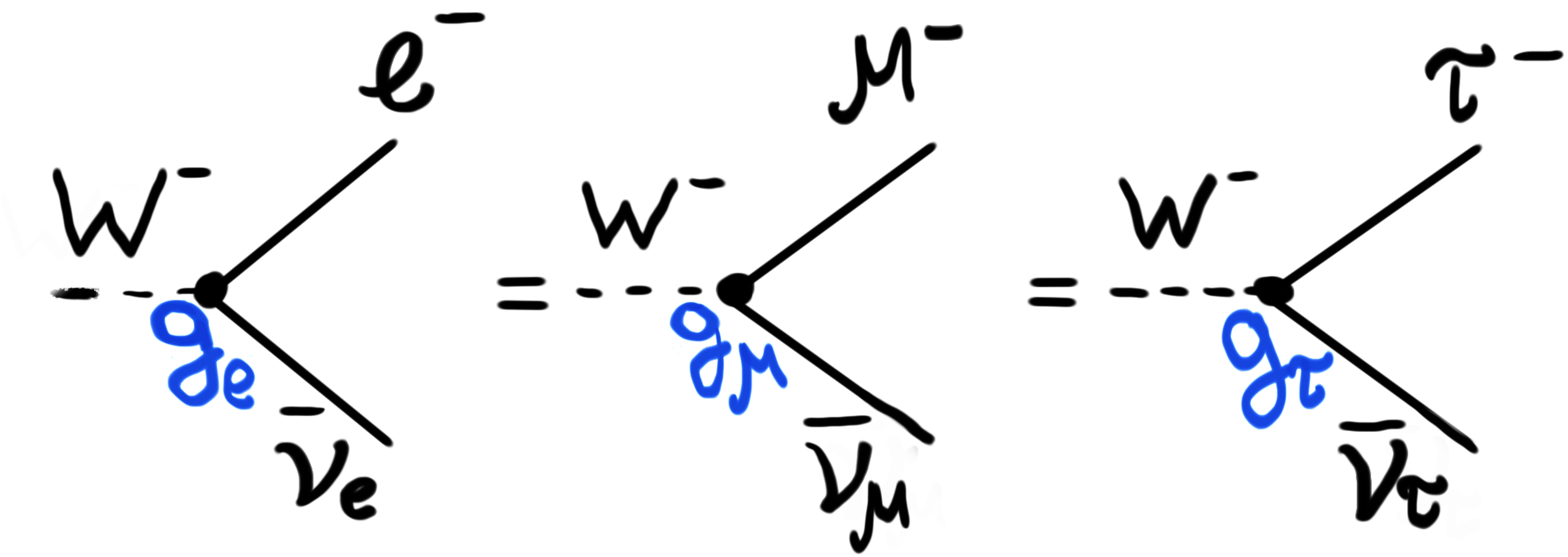
scenario	C_9^{NP}	C_{10}^{NP}	C'_9	C'_{10}
I	-1.4	0	0	0
II	-0.7	0.7	0	0
III	0	0	0.3	0.3
IV	0	0	0.3	-0.3





[LHCB-PUB-2018-009] arXiV:1808.08865

Testing the lepton flavour universality

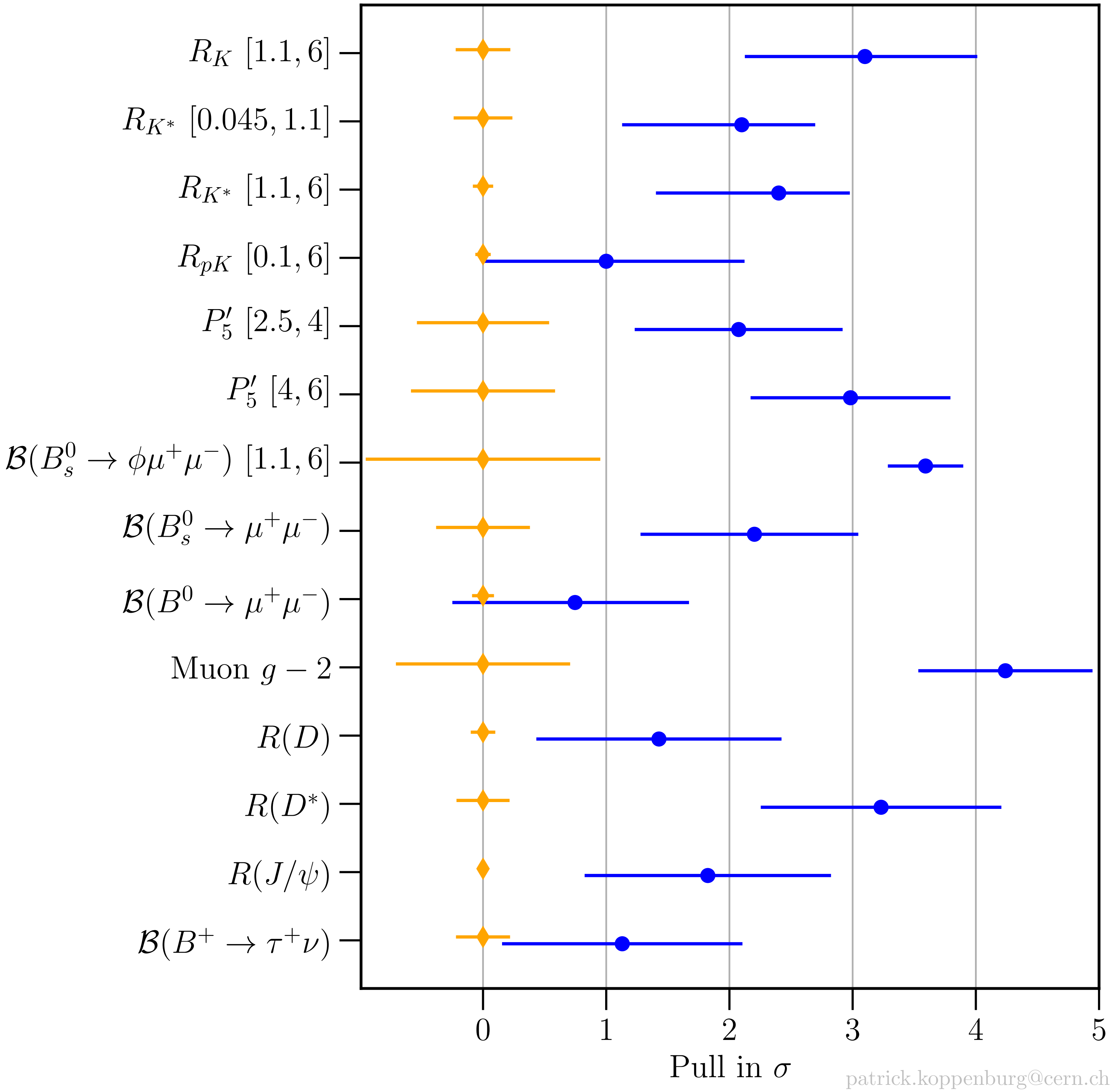


Intrinsic to the SM

Look elsewhere?

(Some of the) Anomalies

Image credit Patrick Koppenburg
https://www.nikhef.nl/~pkoppenb/anomalies.html



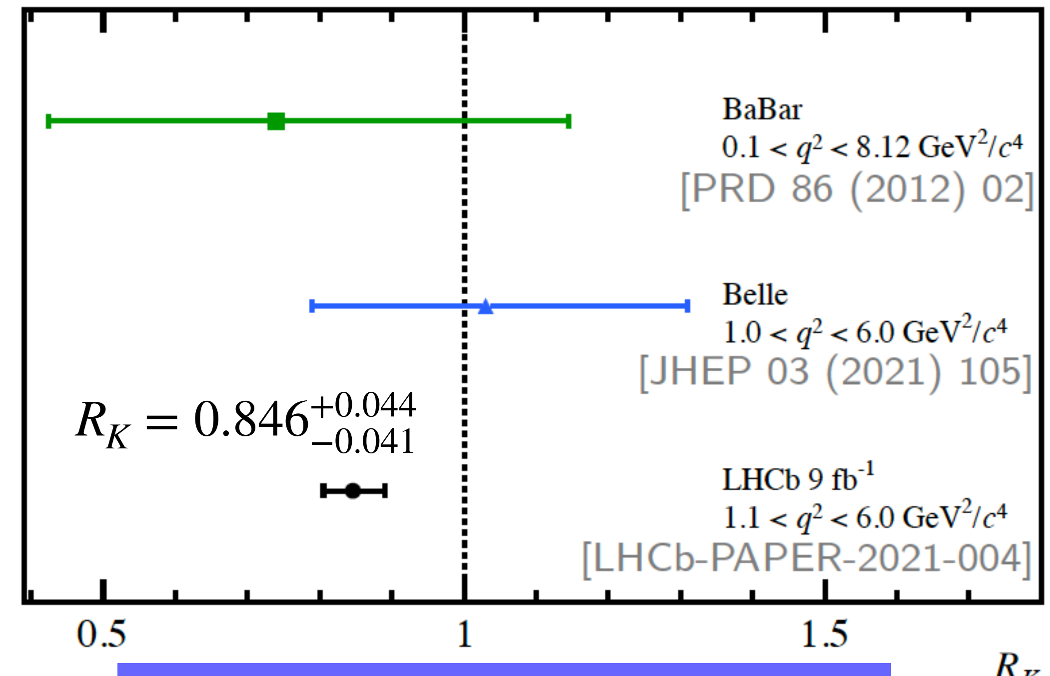
LFU in b→sll transitions

- Theoretically very clean $R_K = 1 + \mathcal{O}(10^{-2})$
- Experimentally very clean:
  - Measured as a double ratio using $B^+ \to K^+ J/\psi(\to \ell^+\ell^-)$ decays

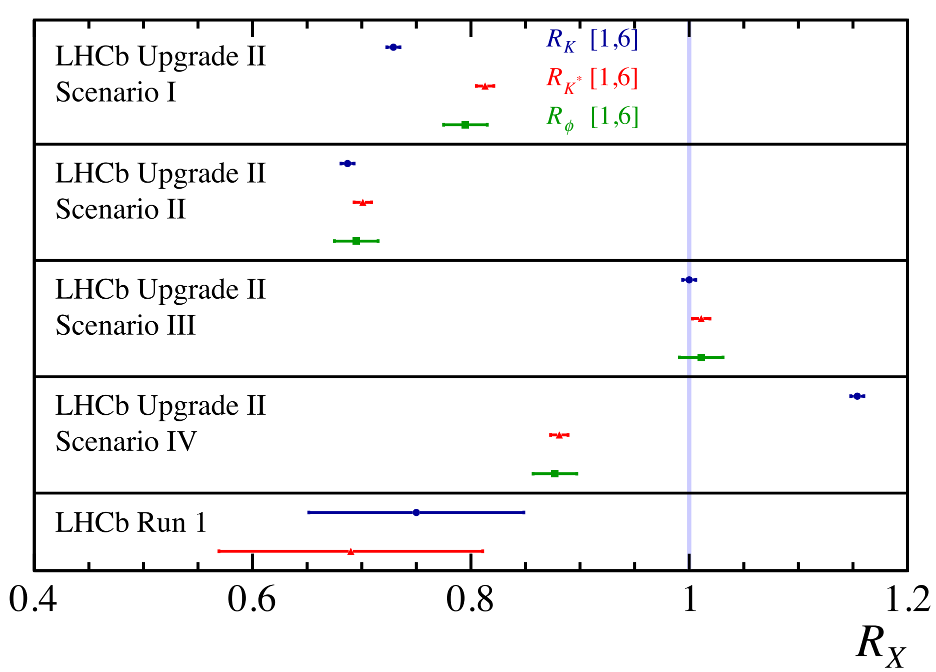
$$R_K = \frac{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to K^+e^+e^-)} \Big/ \frac{\mathcal{B}(B^+ \to K^+J/\psi(\to(\mu^+\mu^-))}{\mathcal{B}(B^+ \to K^+J/\psi(\to(e^+e^-))}$$

- Observation of non-LFU would be a clear sign of new physics

arXiv:2103.11769 submitted to NATURE physics



3.1 σ away from the SM prediction



Yield	Run 1 result	9 fb^{-1}	23 fb^{-1}	50 fb^{-1}	300 fb^{-1}
$B^+ \to K^+e^+e^-$	254 ± 29 [274]	1 120	3 300	7 500	46 000
$B^0 \to K^{*0}e^+e^-$	111 ± 14 [275]	490	1 400	3 300	20 000
$B_s^0 \to \phi e^+e^-$	–	80	230	530	3 300
$\Lambda_b^0 \to pKe^+e^-$	–	120	360	820	5 000
$B^+ \to \pi^+e^+e^-$	–	20	70	150	900
R_X precision	Run 1 result	9 fb^{-1}	23 fb^{-1}	50 fb^{-1}	300 fb^{-1}
R_K	$0.745 \pm 0.090 \pm 0.036$ [274]	0.043	0.025	0.017	0.007
$R_{K^{*0}}$	$0.69 \pm 0.11 \pm 0.05$ [275]	0.052	0.031	0.020	0.008
R_ϕ	–	0.130	0.076	0.050	0.020
R_{pK}	–	0.105	0.061	0.041	0.016
R_π	–	0.302	0.176	0.117	0.047

yields

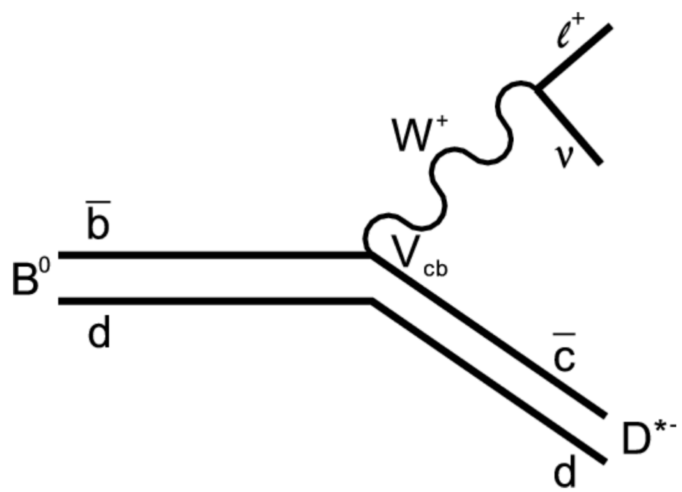
R_X uncertainties

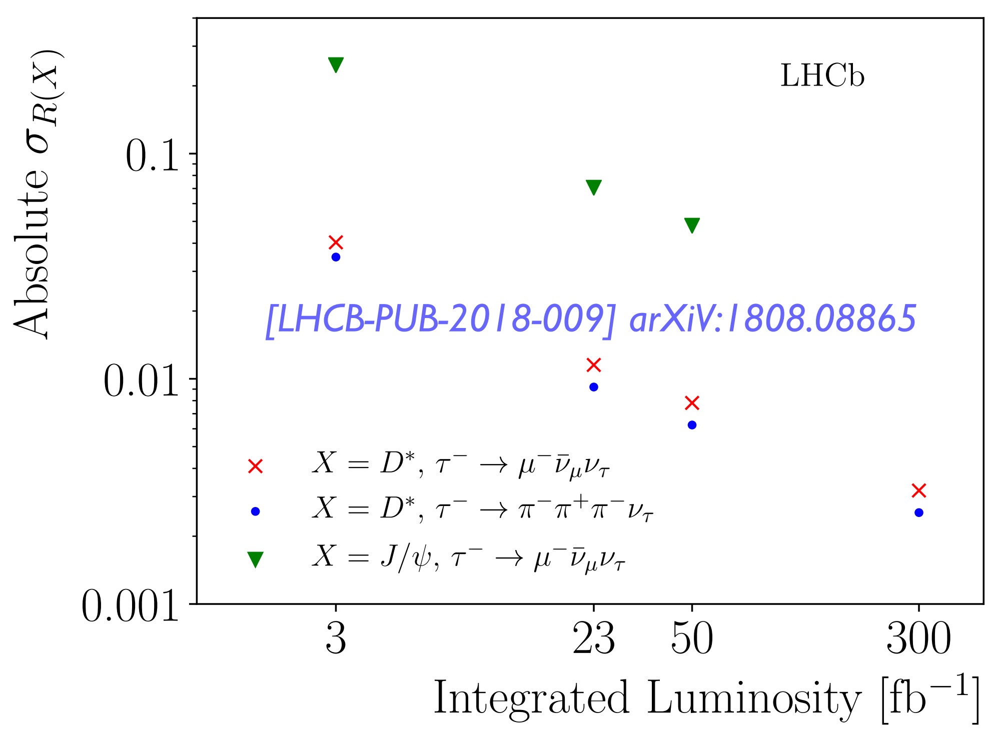
[LHCB-PUB-2018-009] arXiV:1808.08865

Lepton Universality in b→clν transitions

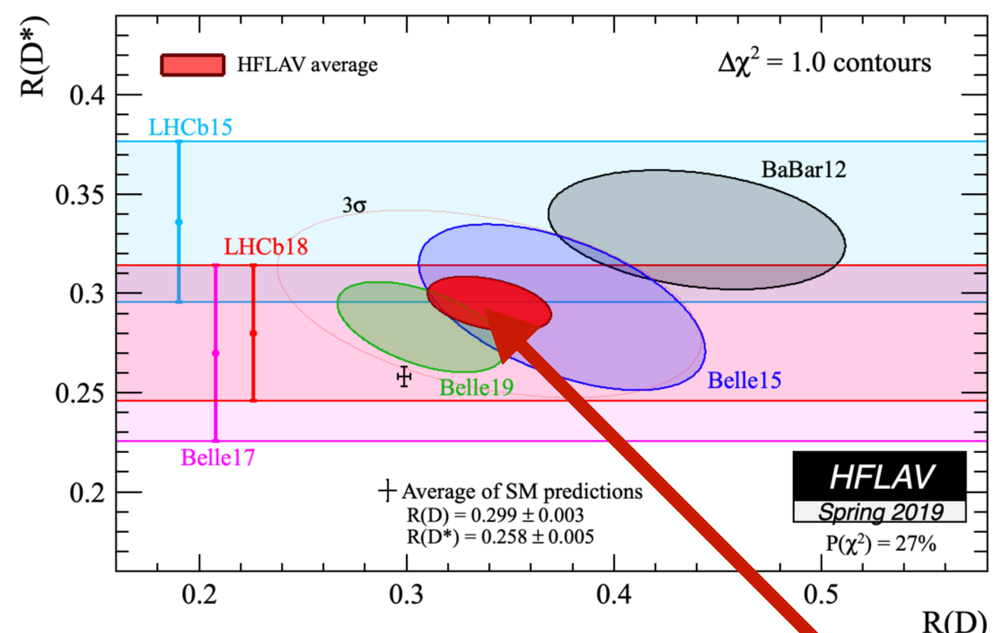
Measure the ratio $R_{D^{(*)}} = \dfrac{\mathscr{B}(B^0 \to D^{(*)}\tau\nu_\tau)}{\mathscr{B}(B^0 \to D^{(*)}\mu\nu_\mu)}$ with $\begin{array}{l} \tau \to \mu\nu_\mu\bar{\nu}_\tau \\ \tau \to \pi\pi\pi(\pi^0)\bar{\nu}_\tau \end{array}$

Tree level decays





[LHCB-PUB-2018-009] arXiV:1808.08865



Combination ~3.1 standard deviations away from SM prediction

More detailed projections in arXiv:2101.08326 and in backup

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Summary

- The flavour physics programme at LHCb is a huge success
  - *#CautiouslyExcited* about the persisting anomalies
  - Many analyses have published results with the full data set
- We need more data to resolve the tensions (and independent confirmations from Belle II, CMS and Atlas are welcome)
- We are installing a fantastic new experiment
- Ambitious plan with R&D on technologies beyond 2030
- The LHCb has expanded enormously its physics case
- We are open to new collaborators to help us expand even further with the full potential of UpgradeII

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BACKUP

Hints about Physics beyond the SM

- Dark Matter existence established at cosmological scale
  - New weakly interacting particles?
- Neutrinos not exactly massless
  - Right-handed (sterile) neutrinos?
- Matter antimatter asymmetry
  - Additional CP violating interactions?

Theories extending the SM introduce a variety of new particles and force carriers to resolve the contradictions between the SM and the observed phenomena

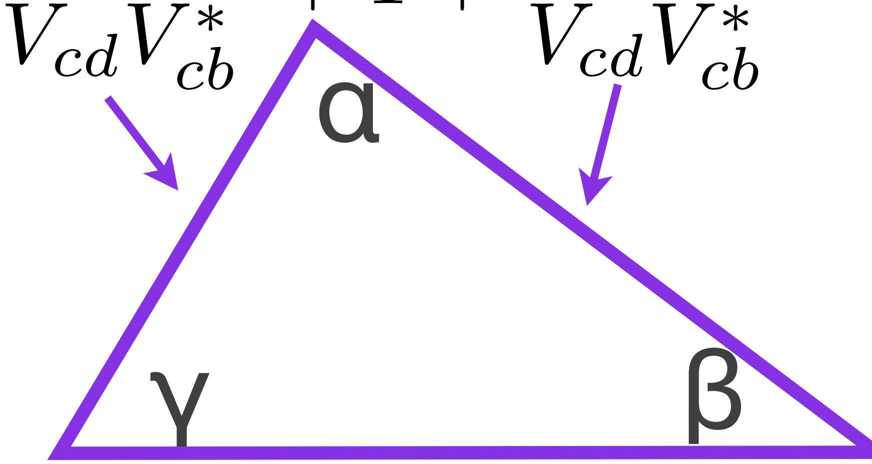
CP violation

- The only established source of CP violation in the SM is contained in the imaginary part of the CKM matrix governing the quark transitions

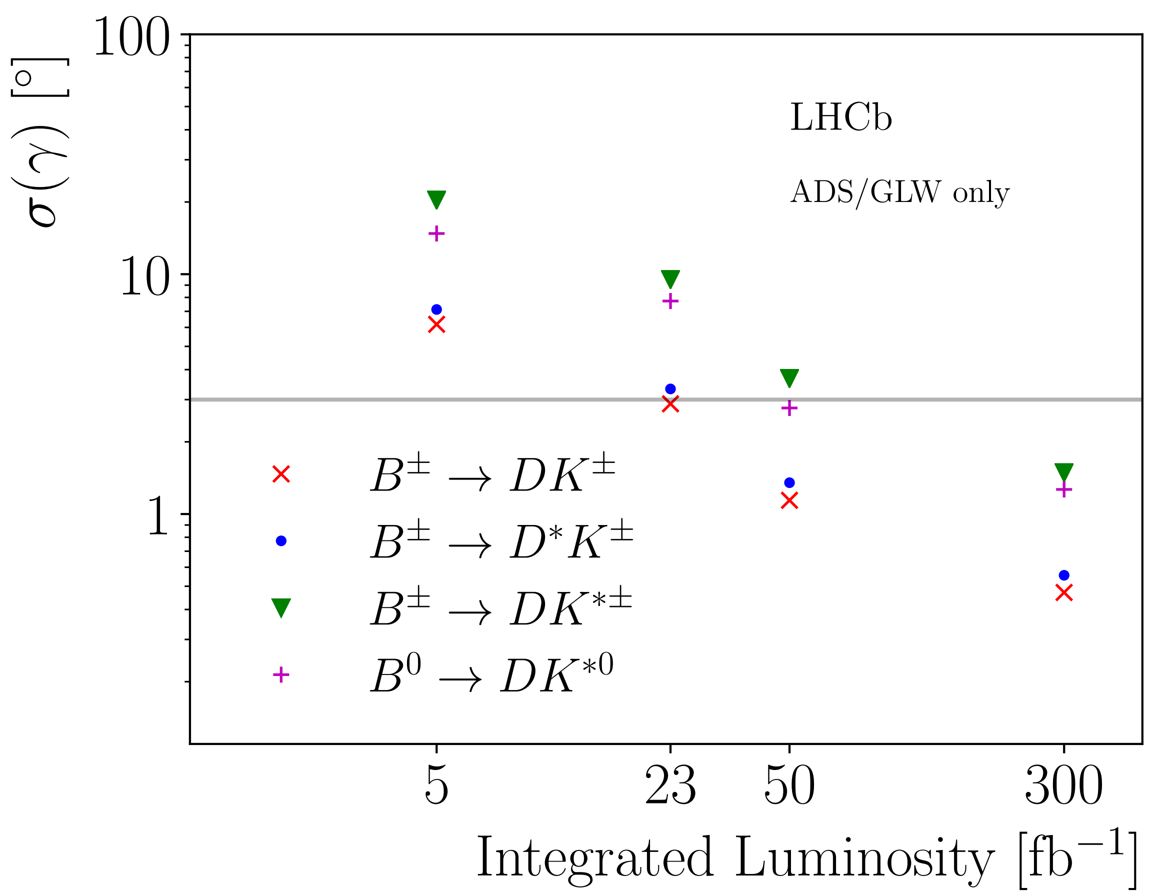
$$V_{\mathrm{CKM}} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

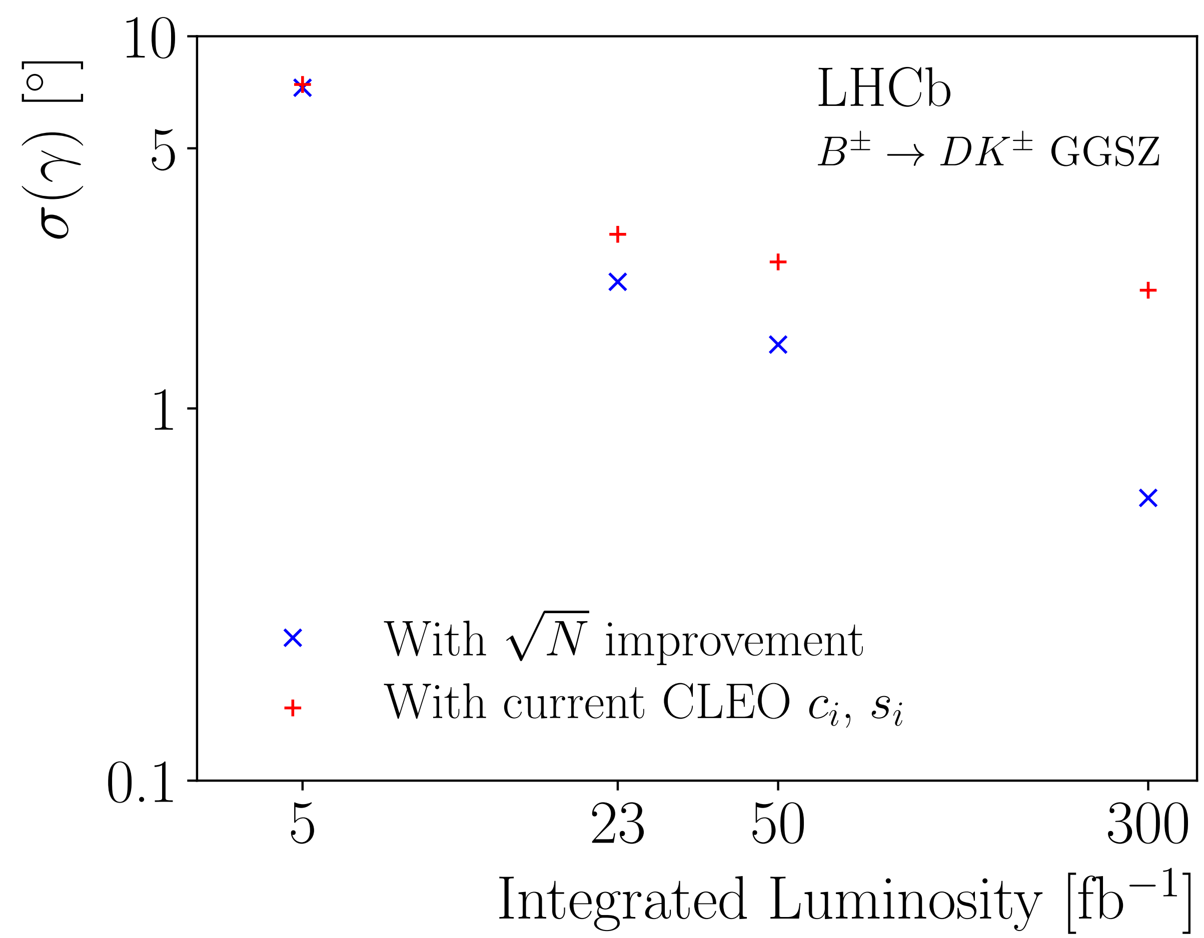
PDG

- Unitary $V_{CKM}V^{\dagger}_{CKM} = 1$ leads to triangles e.g. $\frac{V_{ud}V^*_{ub}}{V_{cd}V^*_{cb}} + 1 + \frac{V_{td}V^*_{tb}}{V_{cd}V^*_{cb}} = 0$



Projections on the CKM angle γ sensitivity with the LHCb upgrades

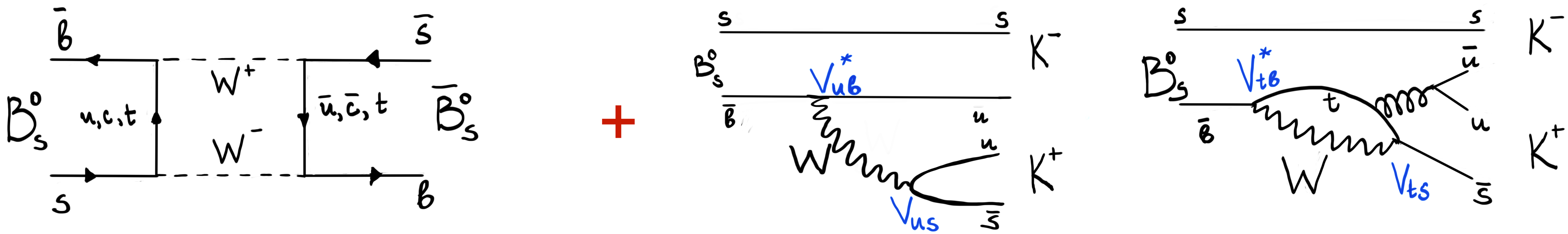




Time - dependent CPV in B_s decays

JHEP 03 (2021) 075

- CPV in charmless B transitions in oscillations AND decay



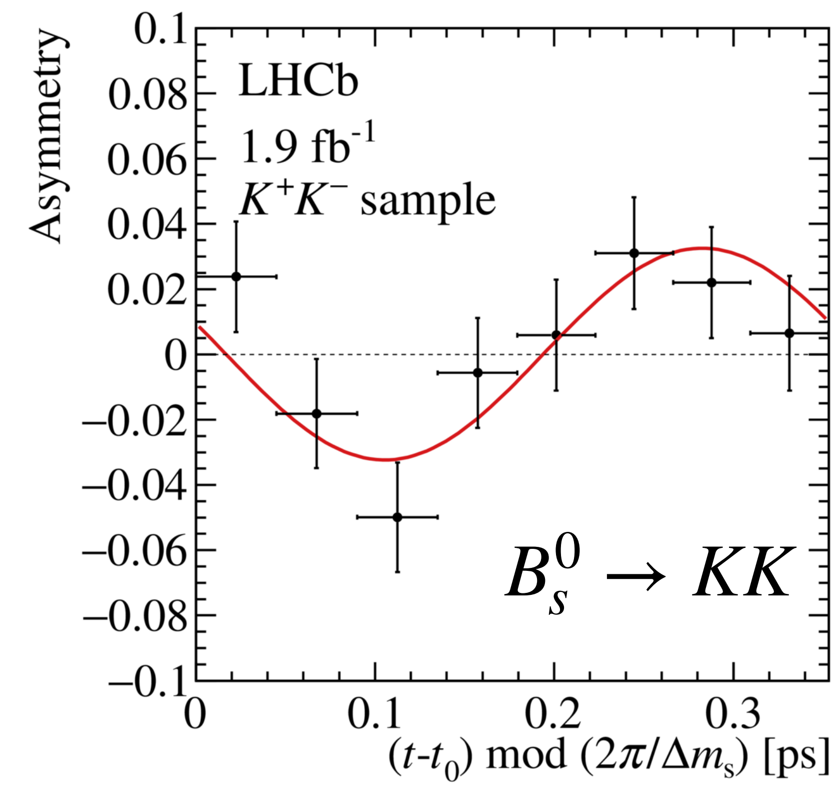
$$A_f(t) = \frac{\Gamma(\bar{B}^0_{(s)} \to hh) - \Gamma(B^0_{(s)} \to hh)}{\Gamma(\bar{B}^0_{(s)} \to hh) + \Gamma(B^0_{(s)} \to hh)} = \frac{-C_f \cos(\Delta m t) + S_f \sin(\Delta m t)}{\cosh(\Delta\Gamma t/2) + A_f^{\Delta\Gamma} \sinh(\Delta\Gamma t/2)}$$

- Joint analysis, several final states, two methods
- Run I + 2015, 2016 data sets
- First observation of TD CPV in B_s^0 with 6.5 σ

$$C_{K+K-} = +0.164 \pm 0.034 \pm 0.014$$

$$S_{K+K-} = +0.123 \pm 0.034 \pm 0.015$$

$$A^{\Delta\Gamma}_{K+K-} = -0.83 \pm 0.05 \pm 0.09$$



folded into 1 oscillation period

Upgrade projections

Data sample	$C_{\pi^+\pi^-}$	$S_{\pi^+\pi^-}$	$C_{K^+K^-}$	$S_{K^+K^-}$	$A^{\Delta\Gamma}_{K^+K^-}$
Run 1 ($3\,\text{fb}^{-1}$ [112])	$-0.34 \pm 0.06 \pm 0.01$	$-0.63 \pm 0.05 \pm 0.01$	$0.20 \pm 0.06 \pm 0.02$	$0.18 \pm 0.06 \pm 0.02$	$-0.79 \pm 0.07 \pm 0.10$
			σ (stat.)		
Run 1-3 ($23\,\text{fb}^{-1}$)	0.015	0.013	0.015	0.015	0.018
Run 1-6 ($300\,\text{fb}^{-1}$)	0.004	0.004	0.004	0.004	0.005

Theory perspective

$$\Delta A_{CP}^{\text{Exp.}} = (-15.6 \pm 2.9) \times 10^{-4}$$

Physics Letters B 774 (2017) 235–242

PHYSICS LETTERS B

$$\left|\Delta a_{CP}^{dir}\right| < 0.020 \pm 0.003\%$$

Direct CP asymmetry in $D \to \pi^-\pi^+$ and $D \to K^-K^+$ in QCD-based approach

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[a] Theoretische Physik 1, Naturwissenschaftlich-Technische Fakultät, Universität Siegen, D-57068 Siegen, Germany
[b] Department of Physics and Astronomy, Wayne State University, Detroit, MI 48201, USA
[c] Michigan Center for Theoretical Physics, University of Michigan, Ann Arbor, MI 48196, USA

BSM!

ΔA_{CP} within the Standard Model and beyond

Mikael Chala, Alexander Lenz, Aleksey V. Rusov and Jakub Scholtz

BSM!

$$|\Delta A_{CP}^{\text{SM}}| \leq 3 \times 10^{-4}$$

Z'?

Implications on the first observation of charm CPV at LHCb

Hsiang-nan Li[1*], Cai-Dian Lü[2†], Fu-Sheng Yu[3‡]

[1] *Institute of Physics, Academia Sinica, Taipei, Taiwan 11529, Republic of China*

Lanzhou 730000, People's Republic of China

SM

$$\Delta A_{CP}^{\text{SM}} = (-0.57 \sim -1.87) \times 10^{-3}$$

The Emergence of the $\Delta U = 0$ Rule in Charm Physics

Yuval Grossman* and Stefan Schacht†

of Physics, LEPP, Cornell University, Ithaca, NY 14853, USA

SM

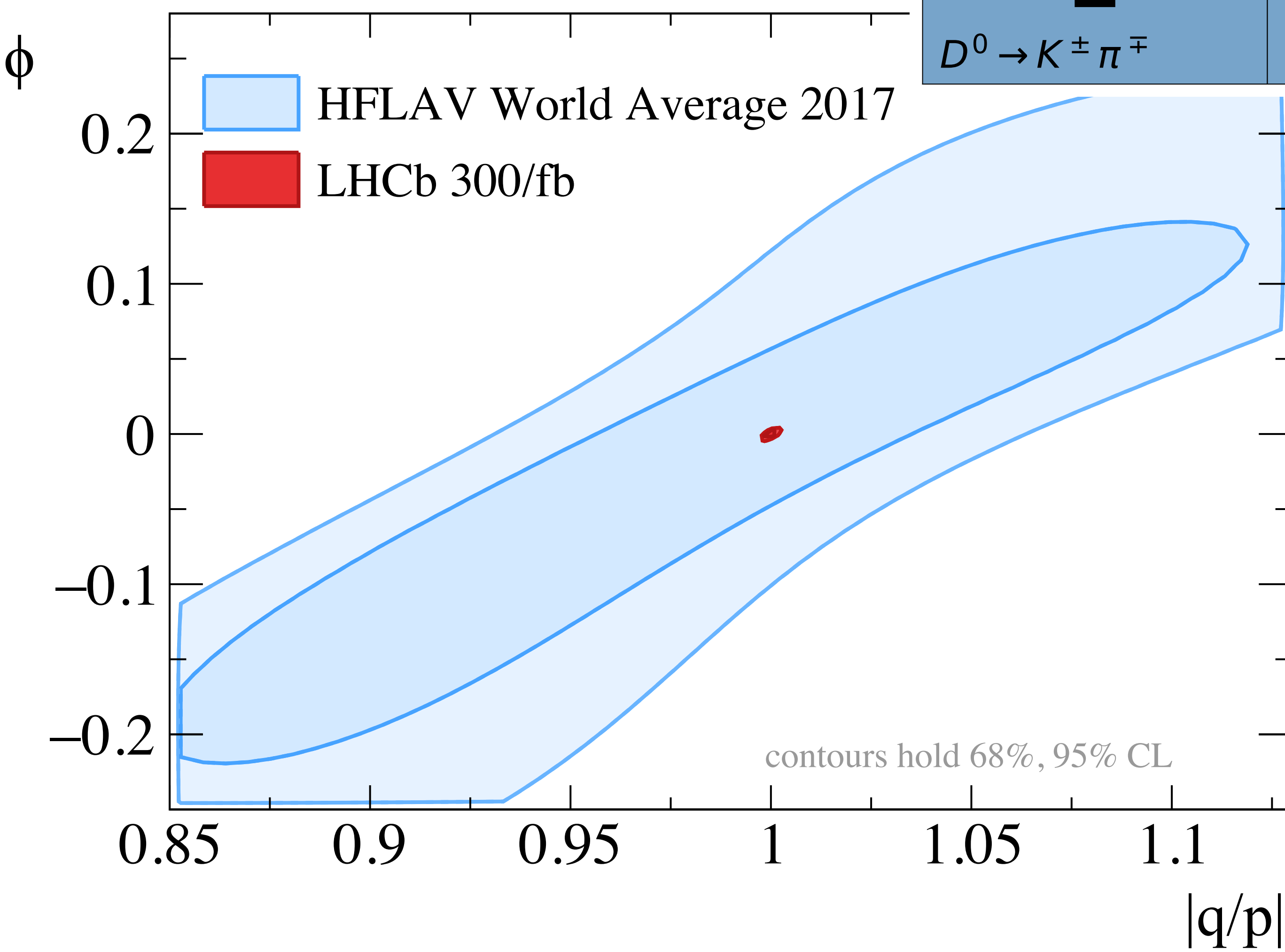
"in SM requires mild non-perturbative enhancement due to rescattering amplitudes"

Making precise SM predictions in the D-meson sector is difficult: Perturbative QCD valid at energies >> 1 GeV; Chiral perturbation theory valid between 0.1 GeV and 1 GeV

D^0 mass = 1.864 GeV

Upgrade sensitivity for charm mixing parameters and indirect CPV

	$D^0 \to K^\pm\pi^\mp$	$D^0 \to K^\mp\pi^\pm\pi^+\pi^-$	$D^0 \to K_S\pi^+\pi^-$	A_Γ
LHCb Current	$\pm 80.0 \times 10^{-5}$	$\pm 96.0 \times 10^{-6}$	$\pm 14.0 \times 10^{-5}$	$\pm 13.0 \times 10^{-5}$
Belle II 2025	$\pm 46.0 \times 10^{-5}$		$\pm 12.0 \times 10^{-5}$	$\pm 35.0 \times 10^{-5}$
LHCb 2025	$\pm 32.0 \times 10^{-5}$	$\pm 40.0 \times 10^{-6}$	$\pm 6.2 \times 10^{-5}$	$\pm 4.3 \times 10^{-5}$
HL-LHC	$\pm 8.0 \times 10^{-5}$	$\pm 8.0 \times 10^{-6}$	$\pm 1.4 \times 10^{-5}$	$\pm 1.0 \times 10^{-5}$



[LHCB-PUB-2018-009] arXiV:1808.08865

Anomalies in b→sμμ transitions

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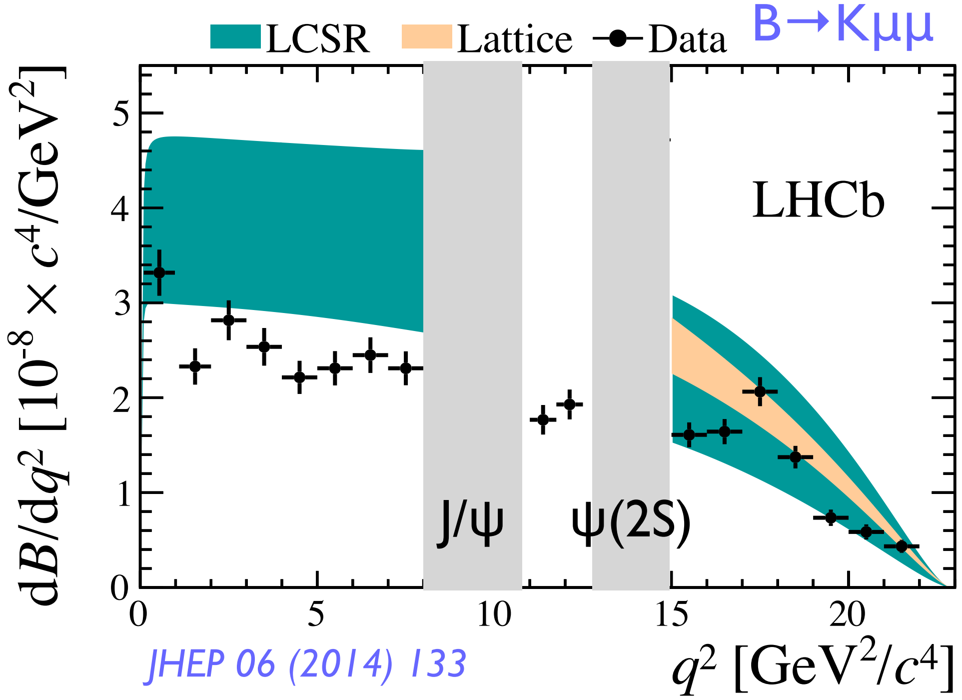
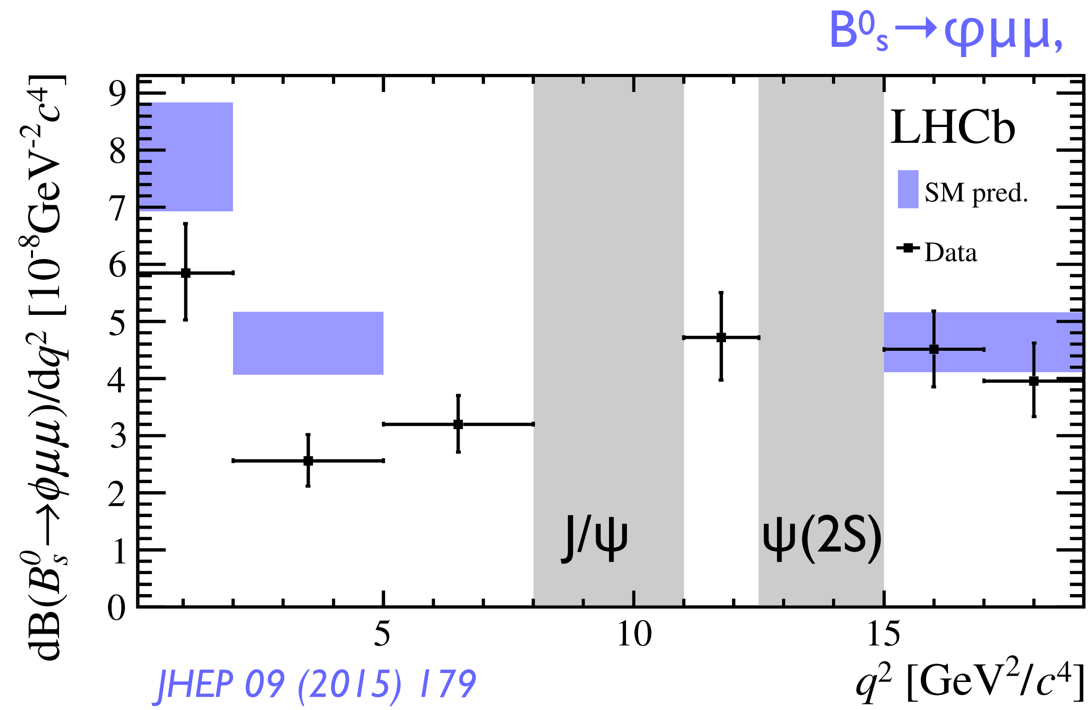
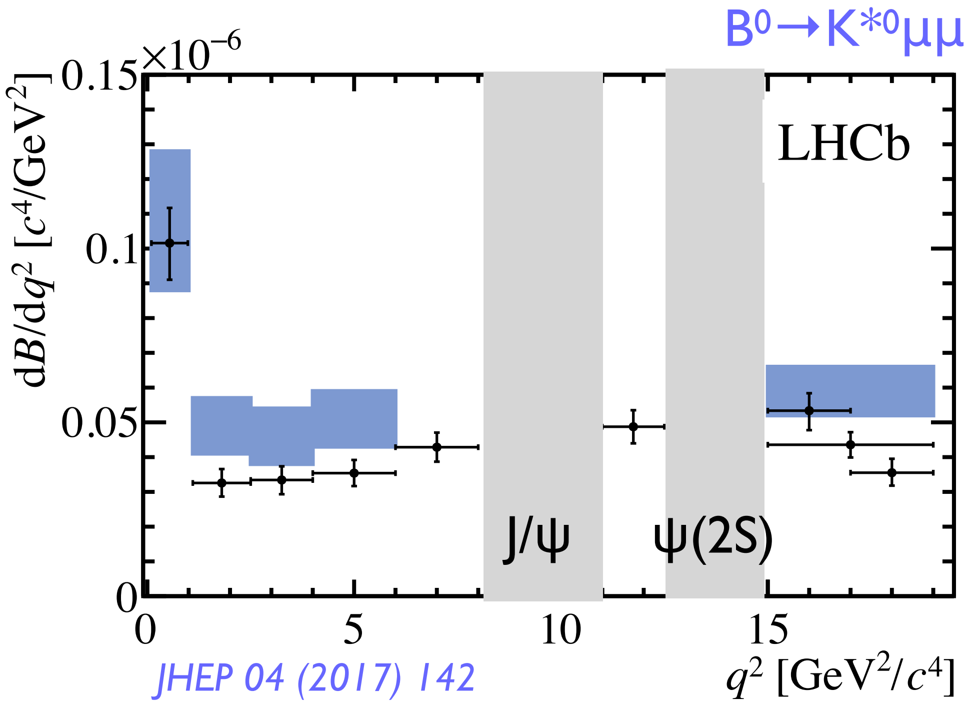
Differential branching fractions consistently lower than SM expectations



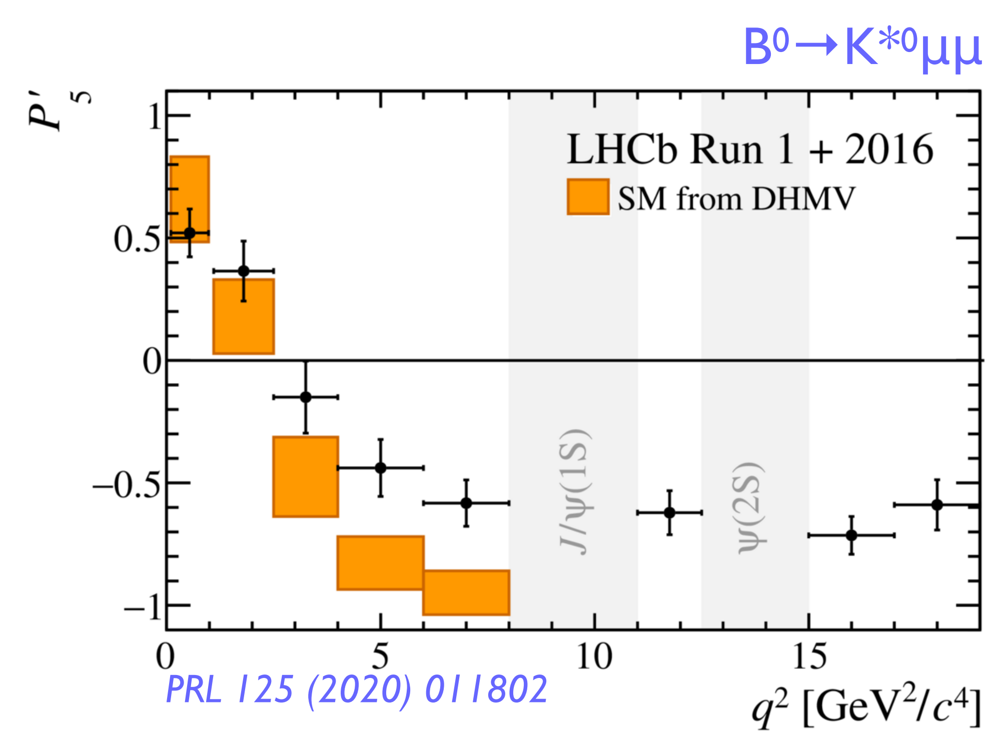
JHEP 06 (2014) 133



JHEP 09 (2015) 179



JHEP 04 (2017) 142



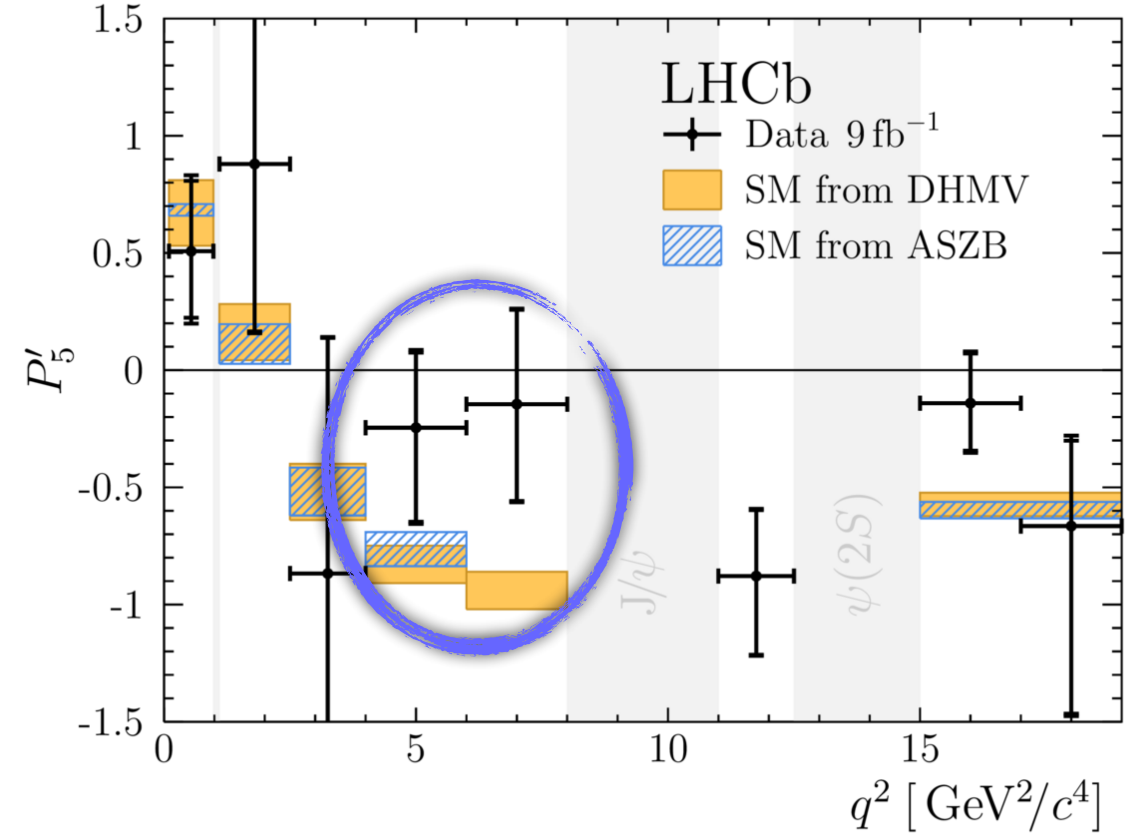
PRL 125 (2020) 011802

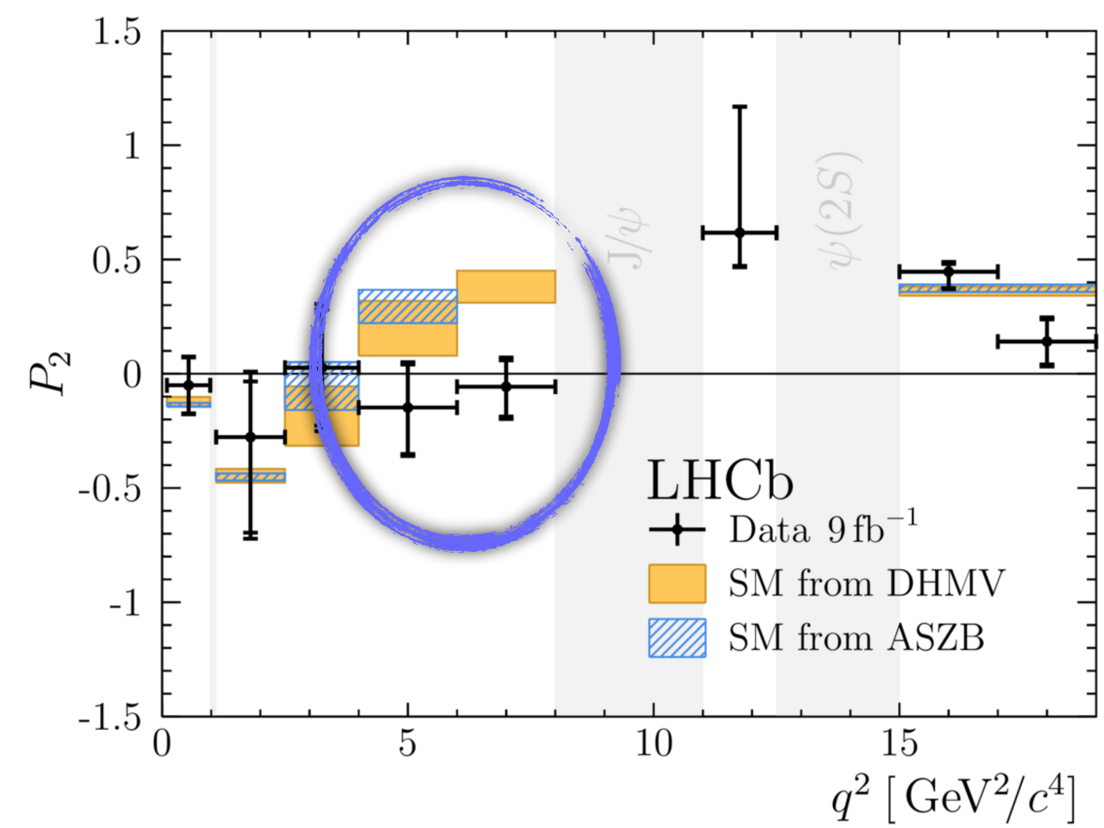
THE ROYAL SOCIETY

Angular analysis of $B^+ \to K^{*+}\mu\mu$

arXiv:2012.13241, submitted to PRL

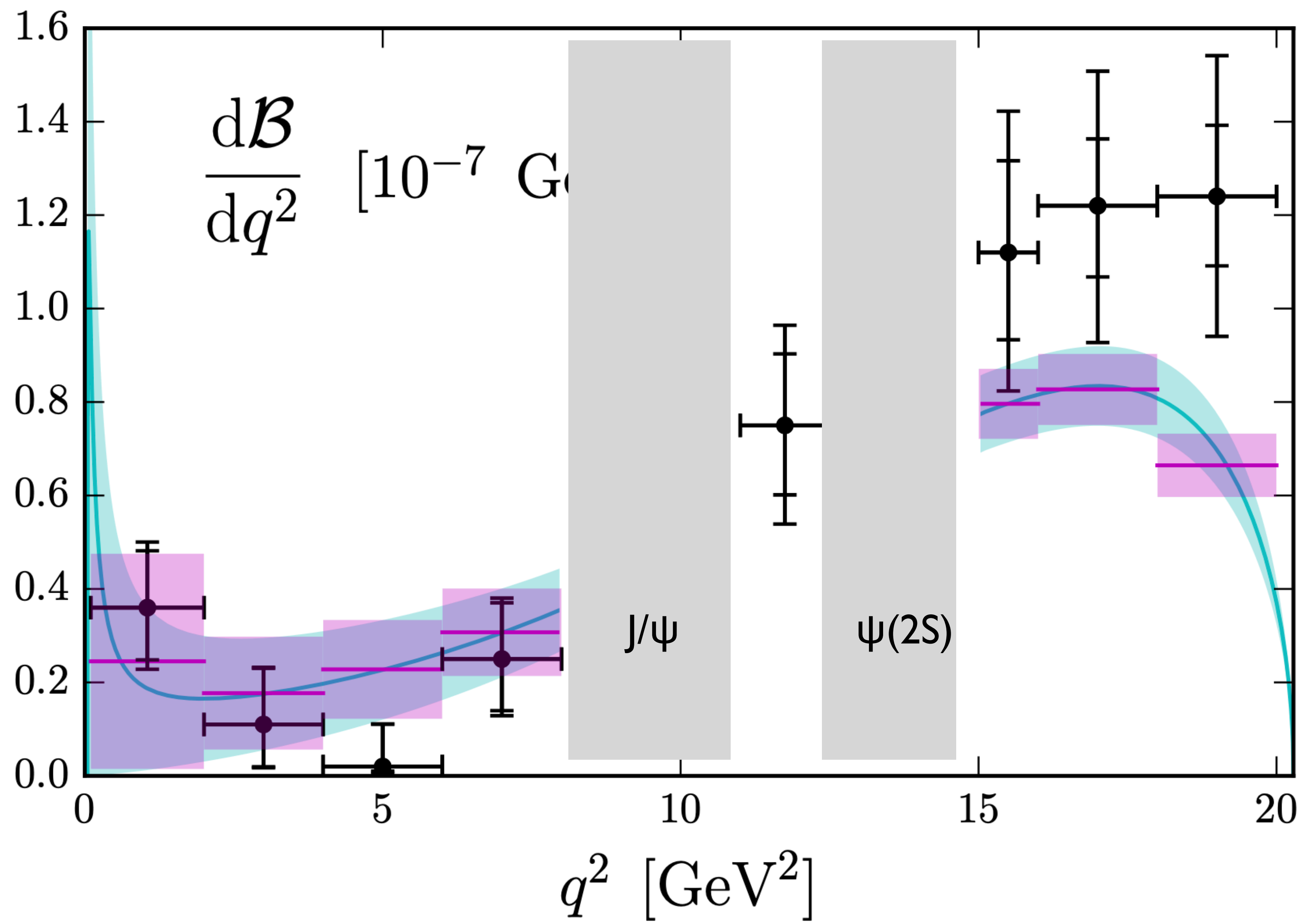
- First angular analysis of $B^+ \to K^{*+}\mu\mu$ at LHCb: 8 angular observables
- Full Run 1+2 data, 9 fb^{-1}
- Evaluate consistency with SM of results in with global fit of the angular observables using Flavio *D. Straub, arXiv:1810.08132*
- Results inconsistent with SM at 3σ level





Further anomalies

$\Lambda^0_b \to \Lambda\mu\mu$

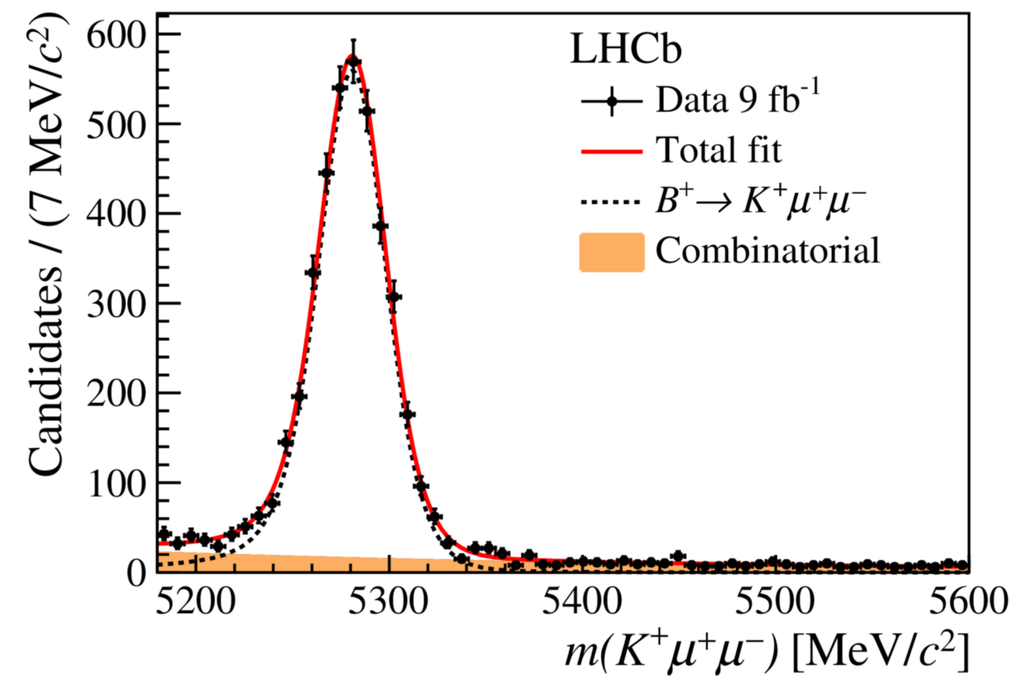


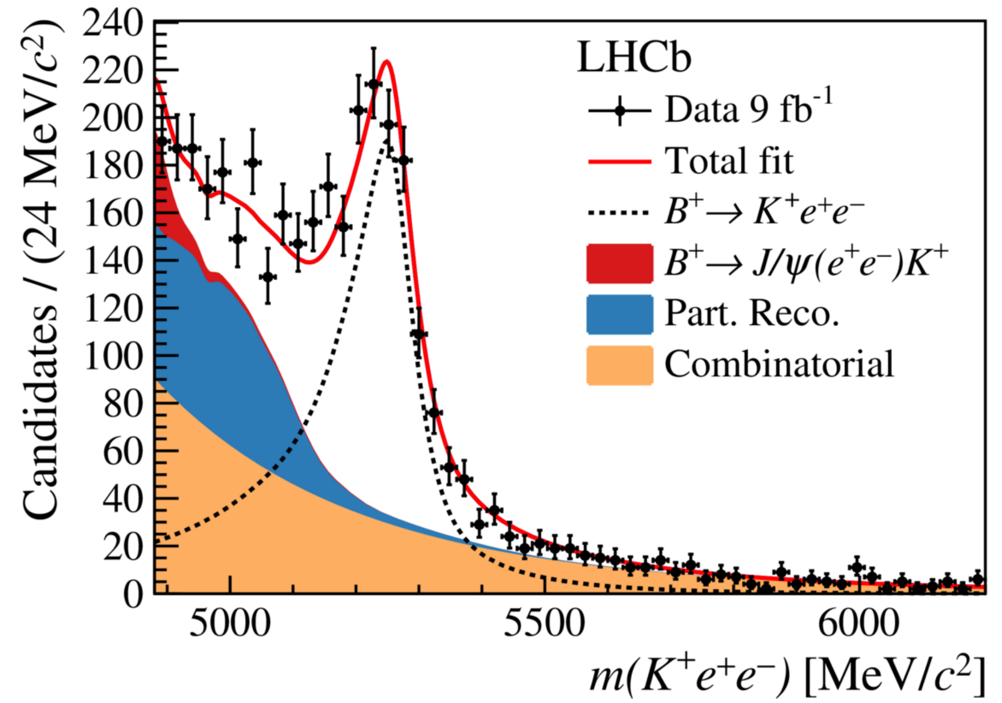
JHEP 06 (2015) 115
Phys.Rev.D 93 (2016) 7, 074501

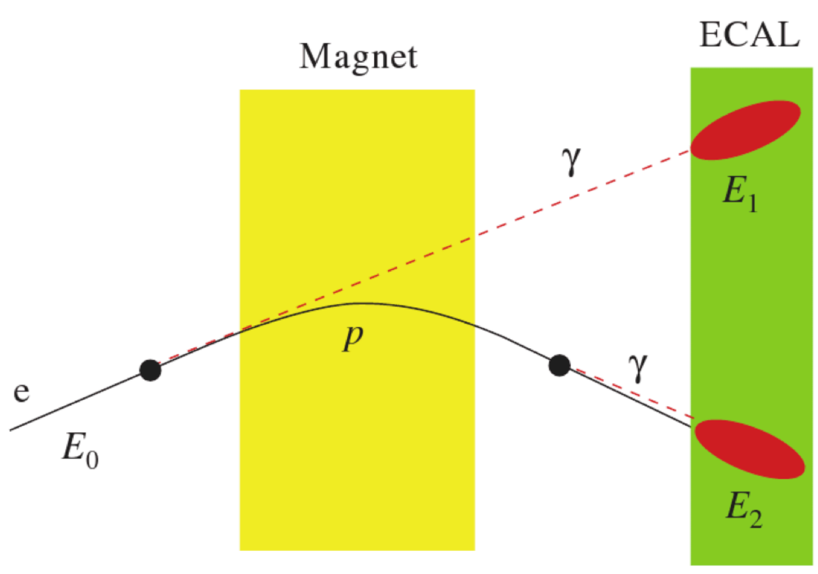
LFU tests at LHCb

- Electron channels are difficult for LHCb
  - Bremsstrahlung leads to energy losses, worse mass shape
  - More difficult to trigger
- Test the ratio $$R_K = \frac{\mathscr{B}(B^+ \to K^+\mu^+\mu^-)}{\mathscr{B}(B^+ \to K^+e^+e^-)}$$

arXiv:2103.11769, submitted to Nature Physics







LFU in b→sll transitions

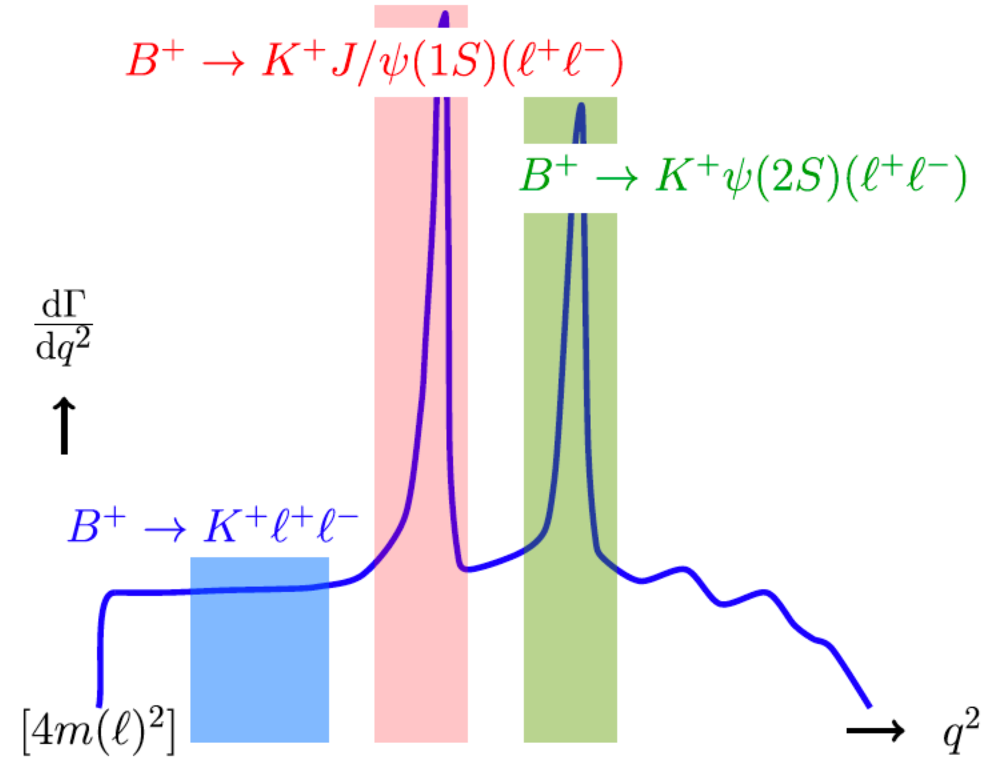
- Theoretically very clean $R_K = 1 + \mathcal{O}(10^{-2})$
- Experimentally very clean:
  - Measured as a double ratio using $B^+ \to K^+ J/\psi(\to \ell^+\ell^-)$ decays

$$R_K = \frac{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to K^+e^+e^-)} \Big/ \frac{\mathcal{B}(B^+ \to K^+J/\psi(\to(\mu^+\mu^-))}{\mathcal{B}(B^+ \to K^+J/\psi(\to(e^+e^-))}$$

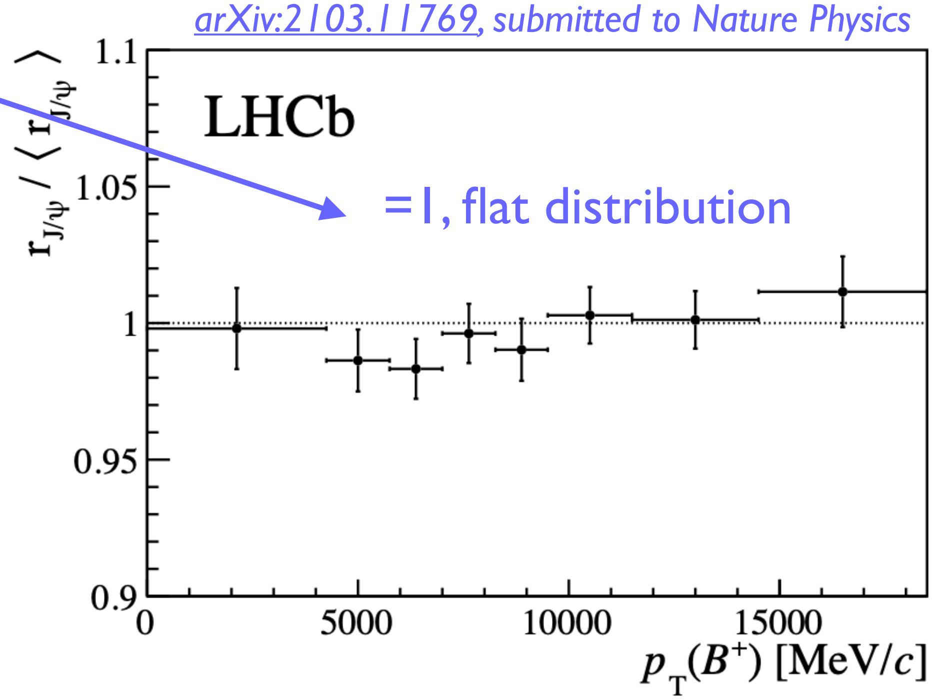
  - Cross check with $B^+ \to K^+\psi(2S)(\to \ell^+\ell^-)$ decays

- Observation of non-LFU would be a clear sign of new physics

Image credit Dan Moise



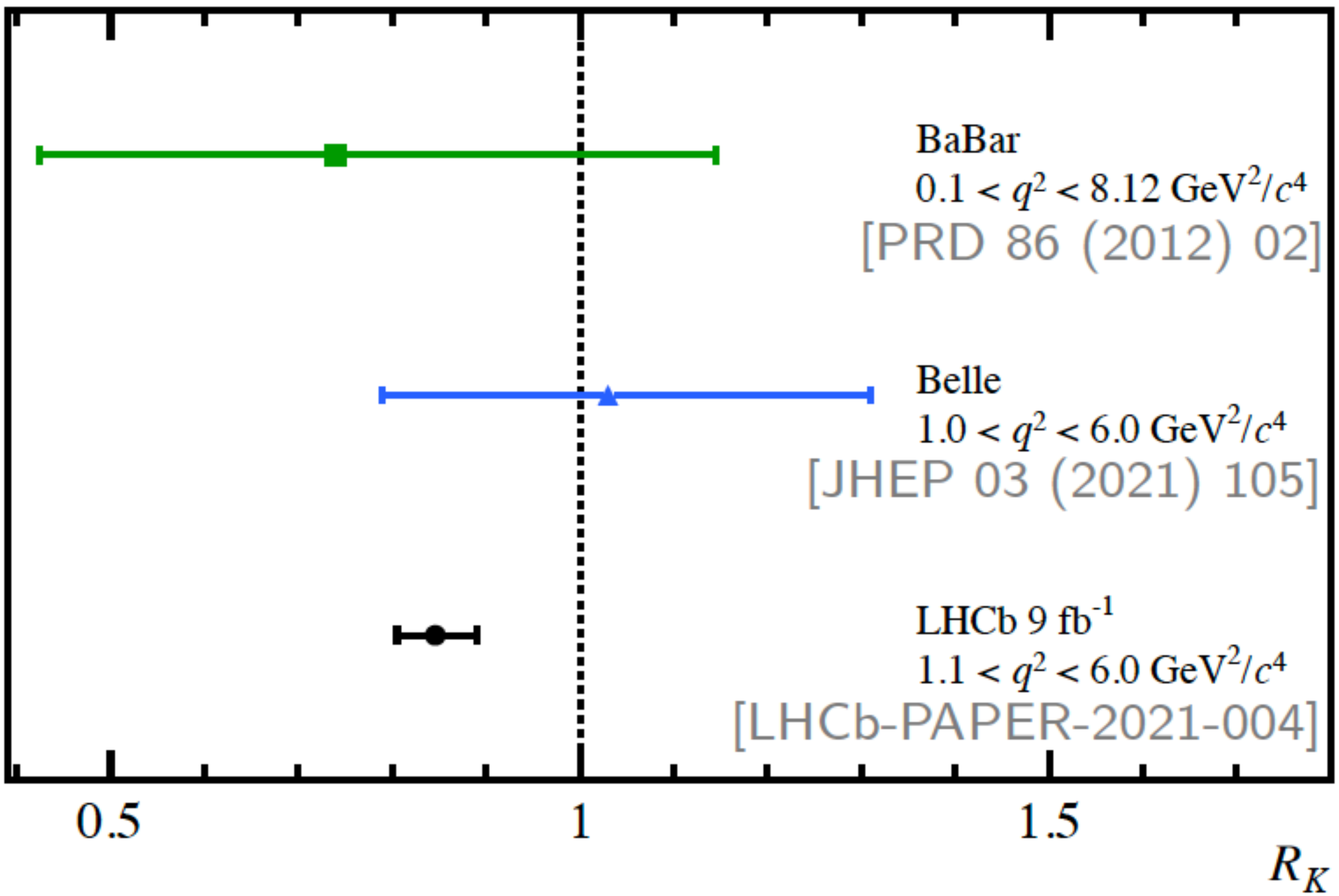
arXiv:2103.11769, submitted to Nature Physics



LFU in $B^+ \to K^+\ell^+\ell^-$

- Full Run 1+2 data, 9 fb^{-1} $R_K = 0.846^{+0.044}_{-0.041}$

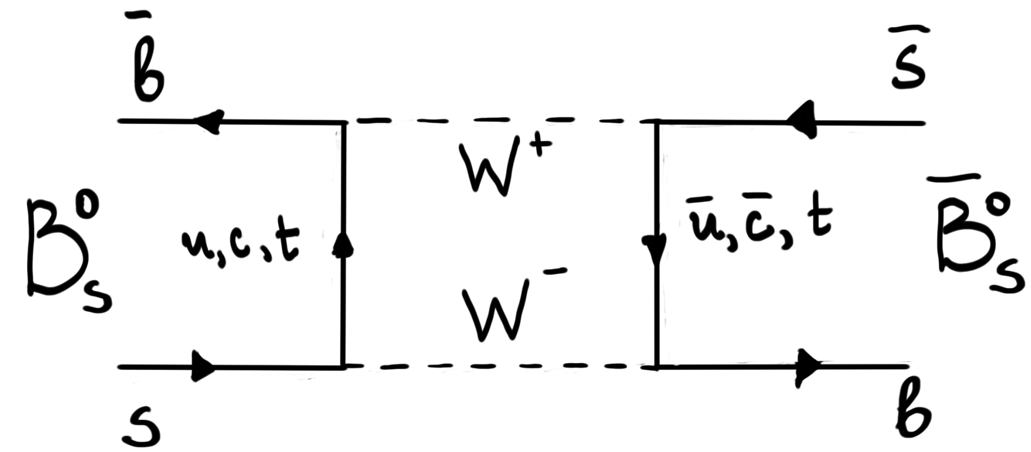
arXiv:2103.11769 submitted to NATURE physics



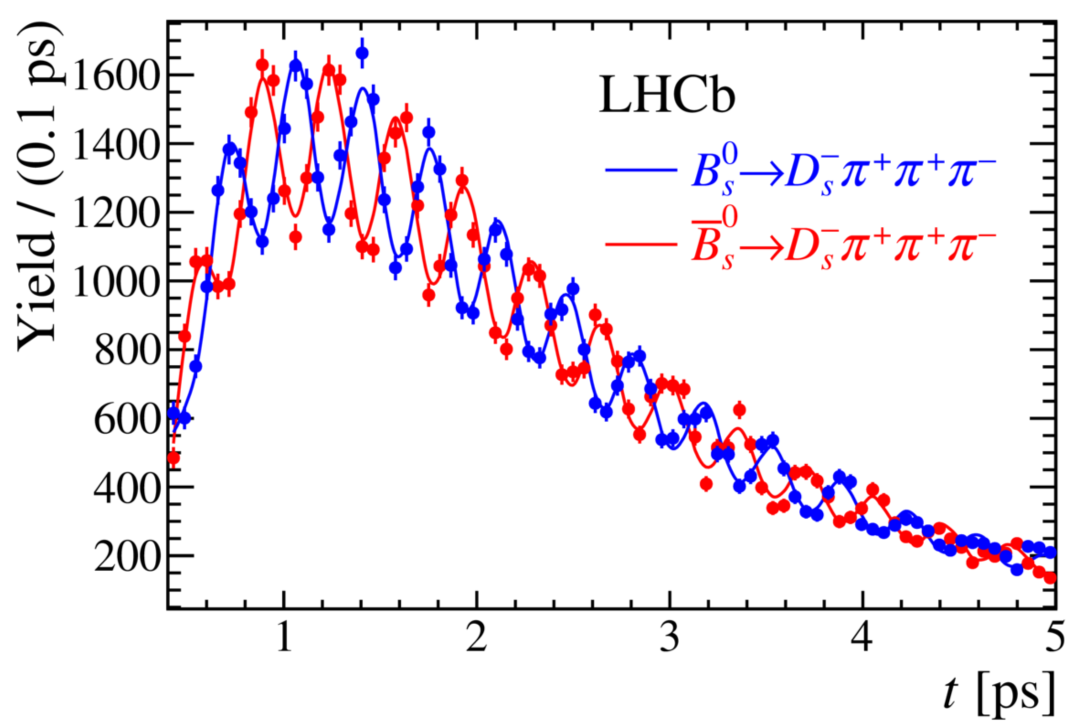
3.1 σ away from the SM prediction

B_s oscillations

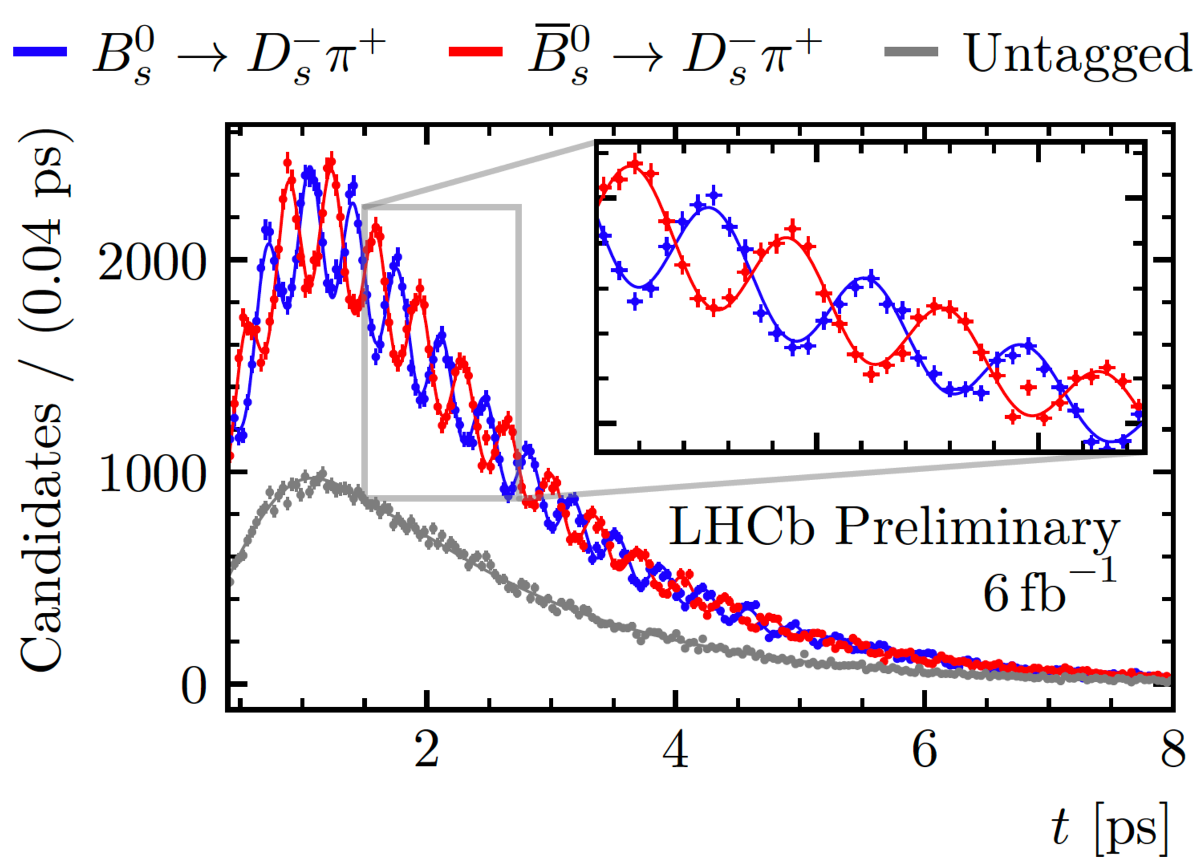
- B_s^0 oscillations are very fast: 3 trillion times per second
- LHCb can only measure them because of the excellent time resolution
- Use flavour specific decays $B_s^0 \to D_s^-(\pi^+\pi^-)\pi^+$



JHEP 03 (2021) 137



arXiv:2104.04421,, on arXiv as of today, submitted to Nature Physics

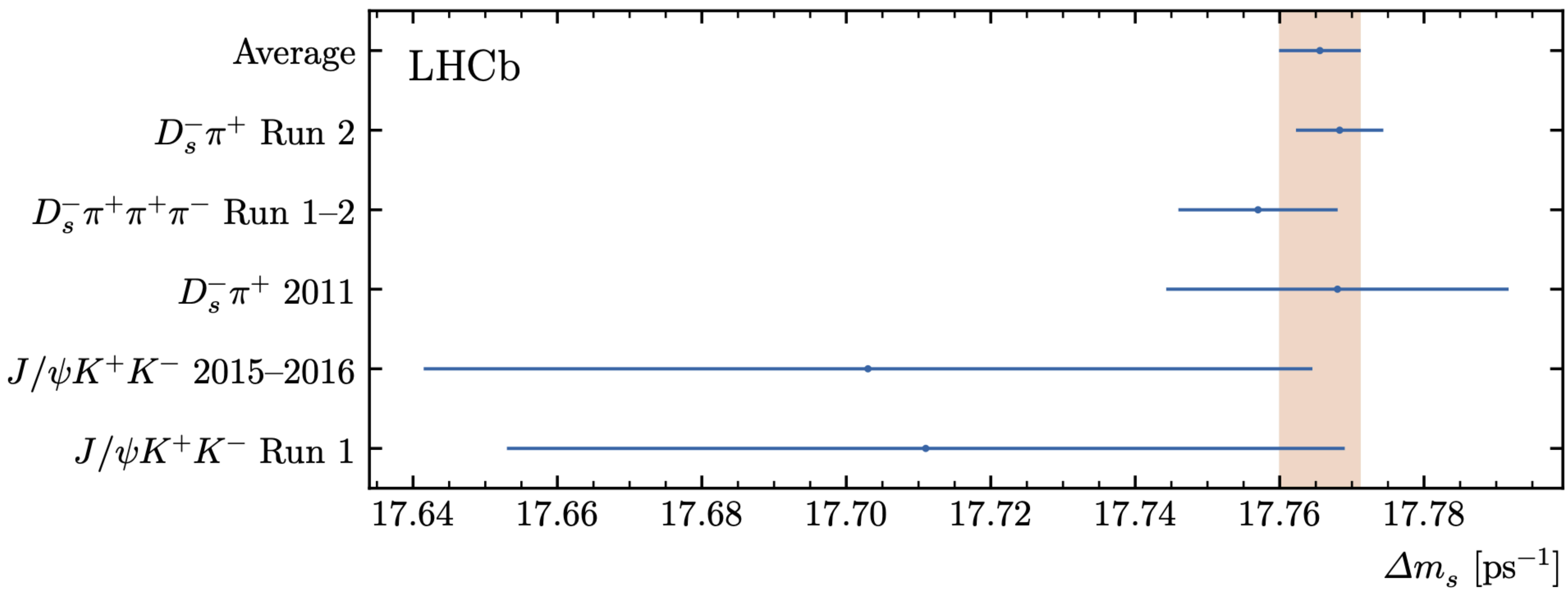


Δm_s combination

- Critical input for time-dependent *CP* Violation measurements

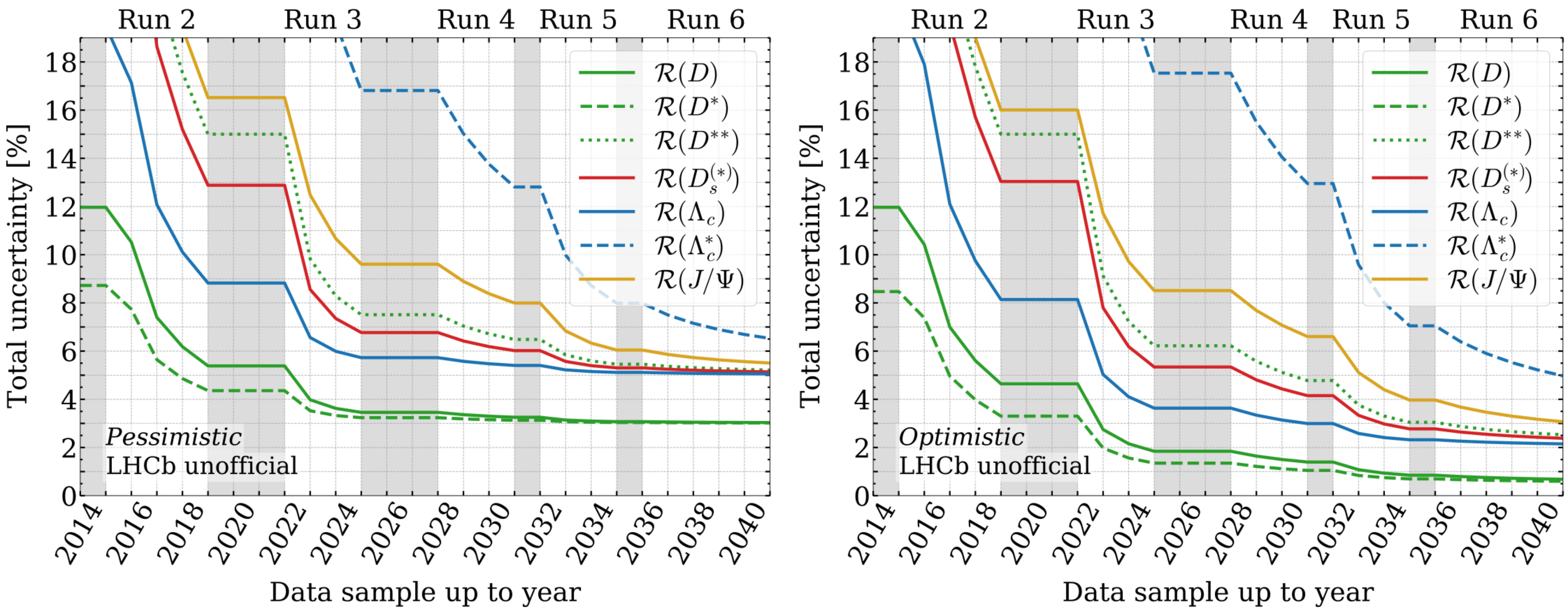
Legacy Run I+II measurement: $\Delta m_s = 17.7656 \pm 0.0057$ ps^{-1}

arXiv:2104.04421, on arXiv as of today, submitted to Nature Physics



SM expectation: $\Delta m_s = 18.4^{+0.7}_{-1.2}$ ps^{-1} *JHEP 12 (2019) 009*

Projections arXiv: 2101.08326



Projections for the expected precision on the measurement of selected R(Hc) ratios at LHCb as a function of the year in which the corresponding data sample becomes available. Left: pessimistic scenario for an irreducible systematic uncertainty of 3% on $R(D^{(*)})$ and 5% on the other ratios. Right: optimistic scenario for an irreducible systematic uncertainty of 0.5% on $R(D^{(*)})$ and 2% on the other ratios. These extrapolations are based on the current muonic-τ measurements of $R(D^{(*)})$ and R(J/ψ), as well as the forthcoming hadronic-τ measurement of $R(D_1^0)$ for the $R(D^{**})$ curve. The $R(\Lambda^*_c)$ entry in the legend refers to $R(\Lambda^*_c$ (2625)). The shaded regions correspond to the long shutdowns during which there is no data taking at the LHC and have been updated including the latest estimates (B´ejar Alonso et al., 2020).

Future sensitivity

		current	$9fb^{-1}$ / $150fb^{-1}$	$23fb^{-1}$ / $300fb^{-1}$	$300fb^{-1}$ / $3000fb^{-1}$
LHCb		current	$9fb^{-1}$	$23fb^{-1}$	$300fb^{-1}$
LHCb	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	$\pm 0.6^{+0.3}_{-0.2} \times 10^{-9}$	${}^{+0.46}_{-0.43}{}^{+0.15}_{-0.11} \times 10^{-9}$	$\pm 0.30 \times 10^{-9}$	$\pm 0.16 \times 10^{-9}$
LHCb	$\frac{\mathcal{B}(B^0 \to \mu^+\mu^-)}{\mathcal{B}(B_s^0 \to \mu^+\mu^-)}$	90 %	70 %	34 %	10 %
LHCb	$\tau_{\mu^+\mu^-}$ (ps)	$\pm 0.44 \pm 0.05$	$\pm 0.29 \pm 0.03$	± 0.16	± 0.04
CMS			$150fb^{-1}$	$300fb^{-1}$	$3000fb^{-1}$
CMS	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	${}^{+0.7}_{-0.6} \pm 0.2 \times 10^{-9}$		$\pm(0.43 - 0.46) \times 10^{-9}$	$\pm(0.39) \times 10^{-9}$
CMS	$\frac{\mathcal{B}(B^0 \to \mu^+\mu^-)}{\mathcal{B}(B_s^0 \to \mu^+\mu^-)}$			50 %	21 %
CMS	$\tau_{\mu^+\mu^-}$ (ps)	${}^{+0.61}_{-0.44}$		± 0.15	± 0.05
ATLAS	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	${}^{+0.8}_{-0.7} \times 10^{-9}$	$\pm 0.83 \times 10^{-9}$		$\pm(0.46 - 0.55) \times 10^{-9}$
ATLAS	$\mathcal{B}(B^0 \to \mu^+\mu^-)$	$< 2.1 \times 10^{-10}$	$\pm 1.43 \times 10^{-10}$		$\pm(0.28 - 0.54) \times 10^{-10}$

[LHCB-PUB-2018-009] [ATL-PHYS-PUB-2018-005] [CMS PAS FTR-14-013/-015]

LHCb projections depend on assumptions of the systematic uncertainty