重味物理前沿论坛研讨会

Workshop of Frontiers in Heavy Flavor Physics

Status of Flavour Anomalies at LHCb

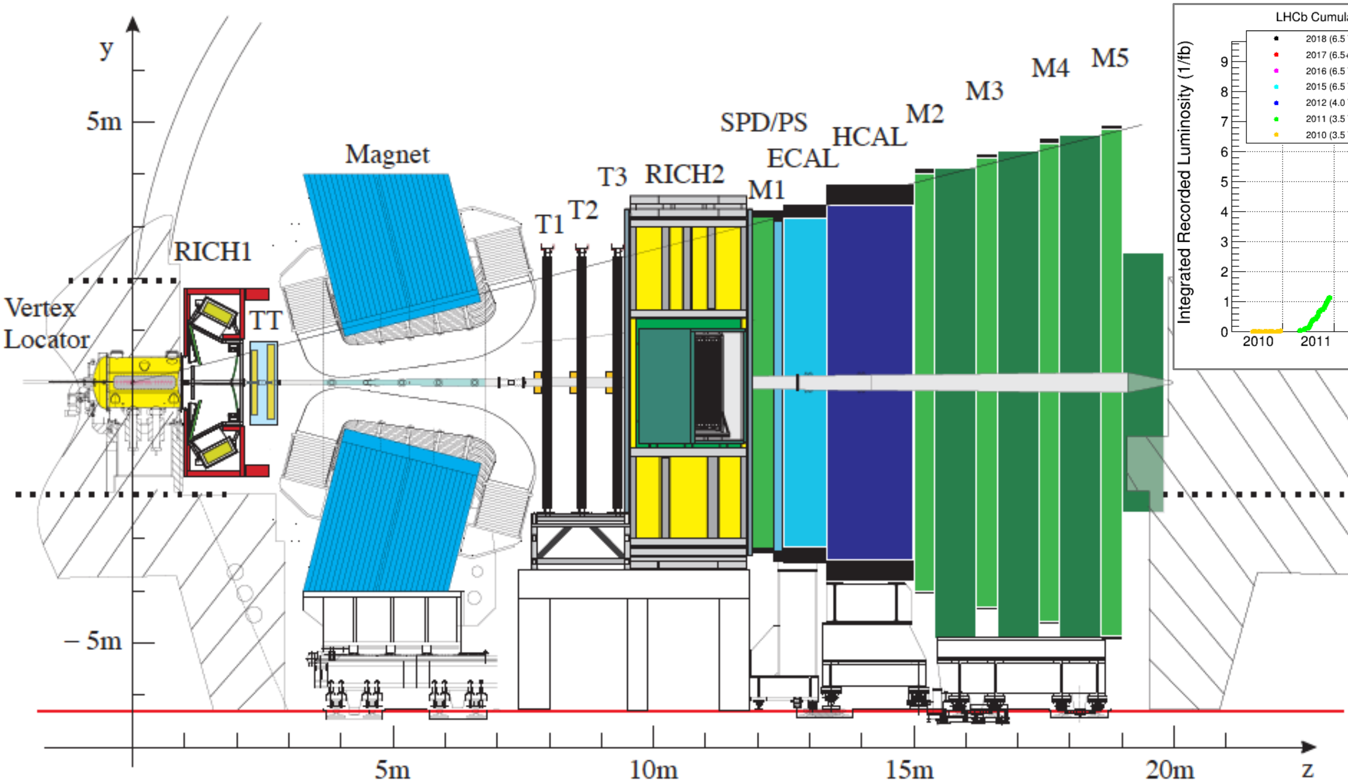
Jibo HE/何吉波（UCAS/中国科学院大学）

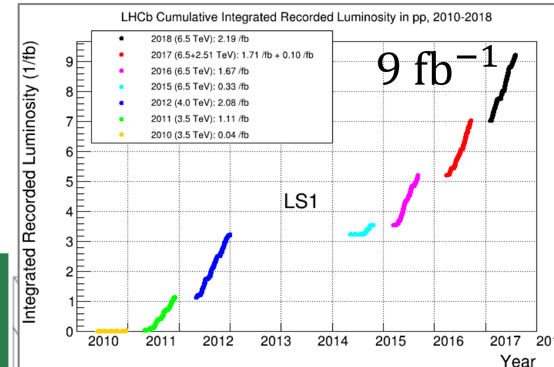
2023年11月24-27日

Large Hadron Collider

Proton energy: up to 7 TeV (10^{12} eV)
speed: 0.999999991 c

The LHCb experiment

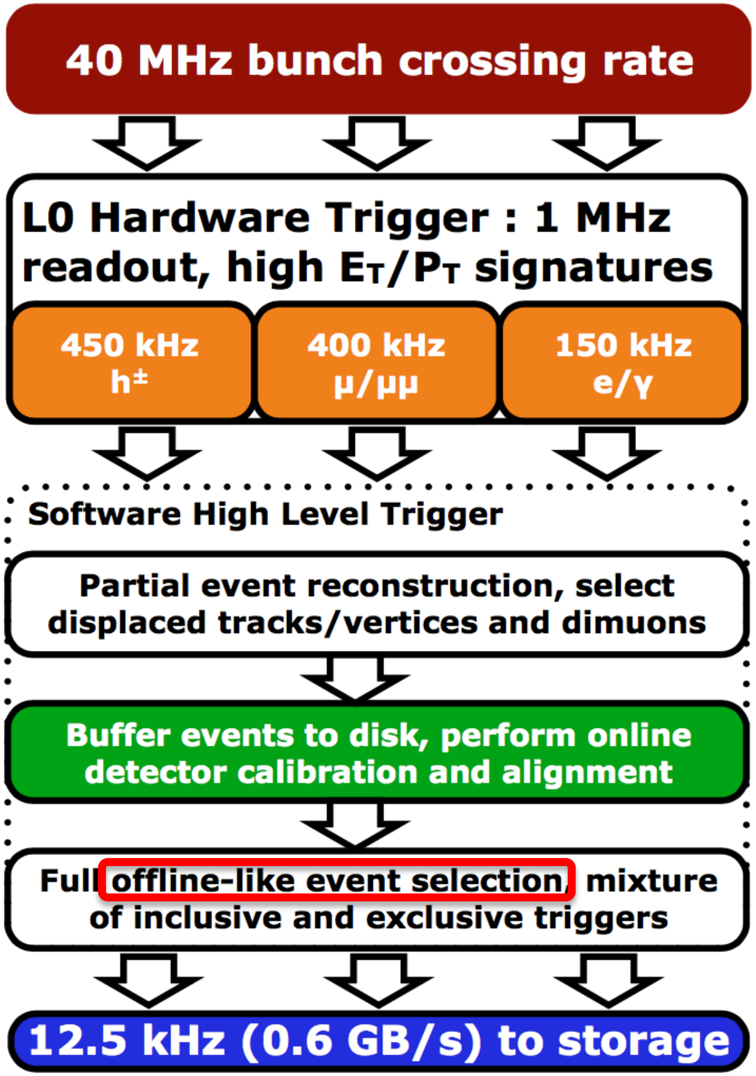




[JINST 3 (2008) S08005]

Vertex Locator	$\sigma_{\mathrm{PV,x/y}} \sim 10\ \mu\mathrm{m}$, $\sigma_{\mathrm{PV,z}} \sim 60\ \mu\mathrm{m}$
Tracking (TT, T1-T3)	$\Delta p/p$: 0.4% at 5 GeV/c, to 0.6% at 100 GeV/c
RICHs	$\varepsilon(K \to K) \sim 95\%$, mis-ID rate $(\pi \to K) \sim 5\%$
Muon system (M1-M5)	$\varepsilon(\mu \to \mu) \sim 97\%$, mis-ID rate $(\pi \to \mu) = 1-3\%$
ECAL	$\sigma_E/E \sim 10\%/\sqrt{E} \oplus 1\%$ (E in GeV)
HCAL	$\sigma_E/E \sim 70\%/\sqrt{E} \oplus 10\%$ (E in GeV)

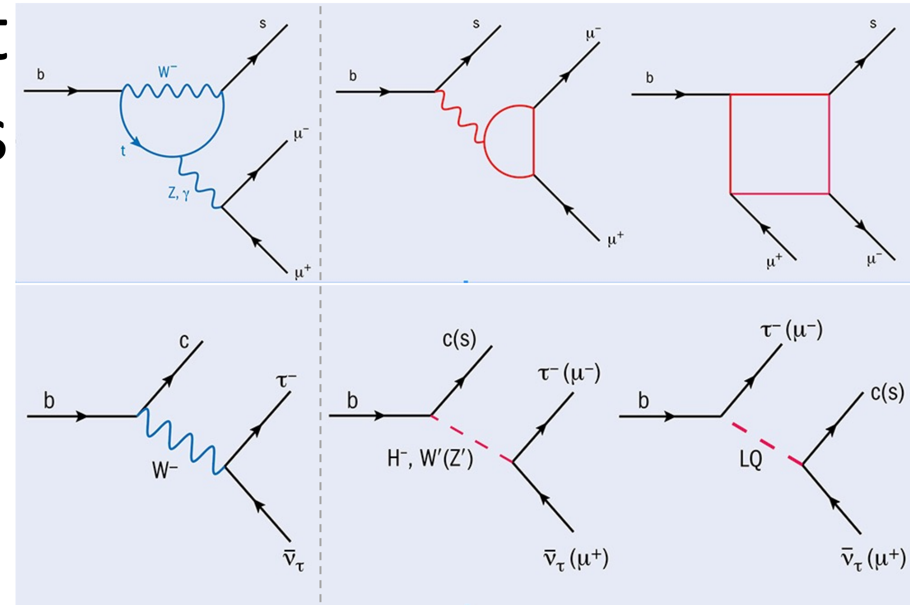
The LHCb trigger (2018)

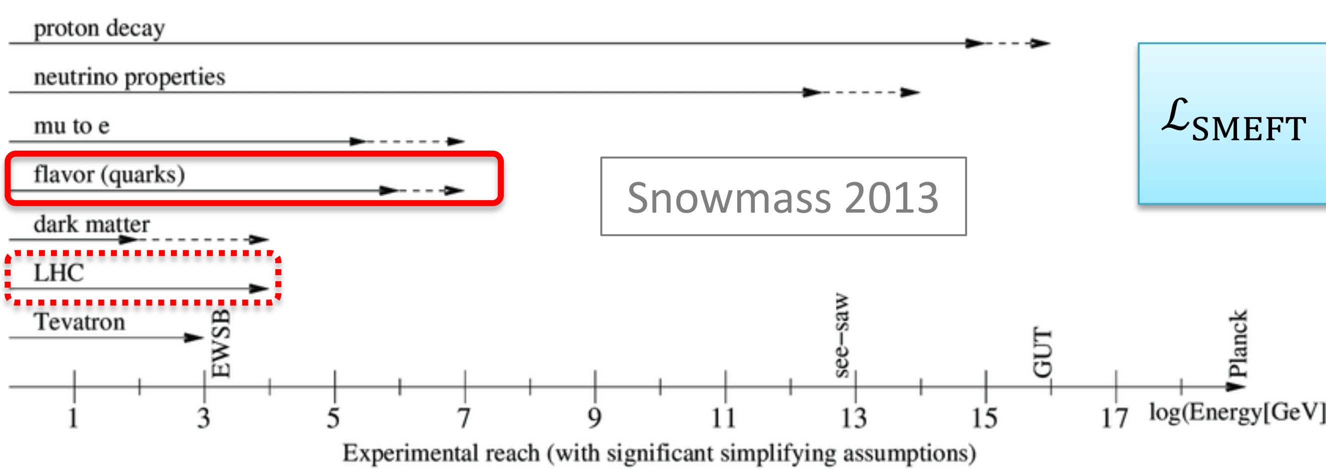


- L0, Hardware
  - $p_T(\mu_1) \times p_T(\mu_2) >$ (1.5 GeV)^2
  - $p_T(\mu) >$ 1.8 GeV
  - $E_T(e) >$ 2.4 GeV
  - $E_T(\gamma) >$ 3.0 GeV
  - $E_T(h) >$ 3.7 GeV
- High Level Trigger
  - Stage1, p_T, IP
  - Stage2, full selection

Indirect search for New Physics

- Precision measurement of heavy hadron decays
  - Flavour-Changing NC
  - Flavour-Changing CC
- Probe New Physics at high energy scale



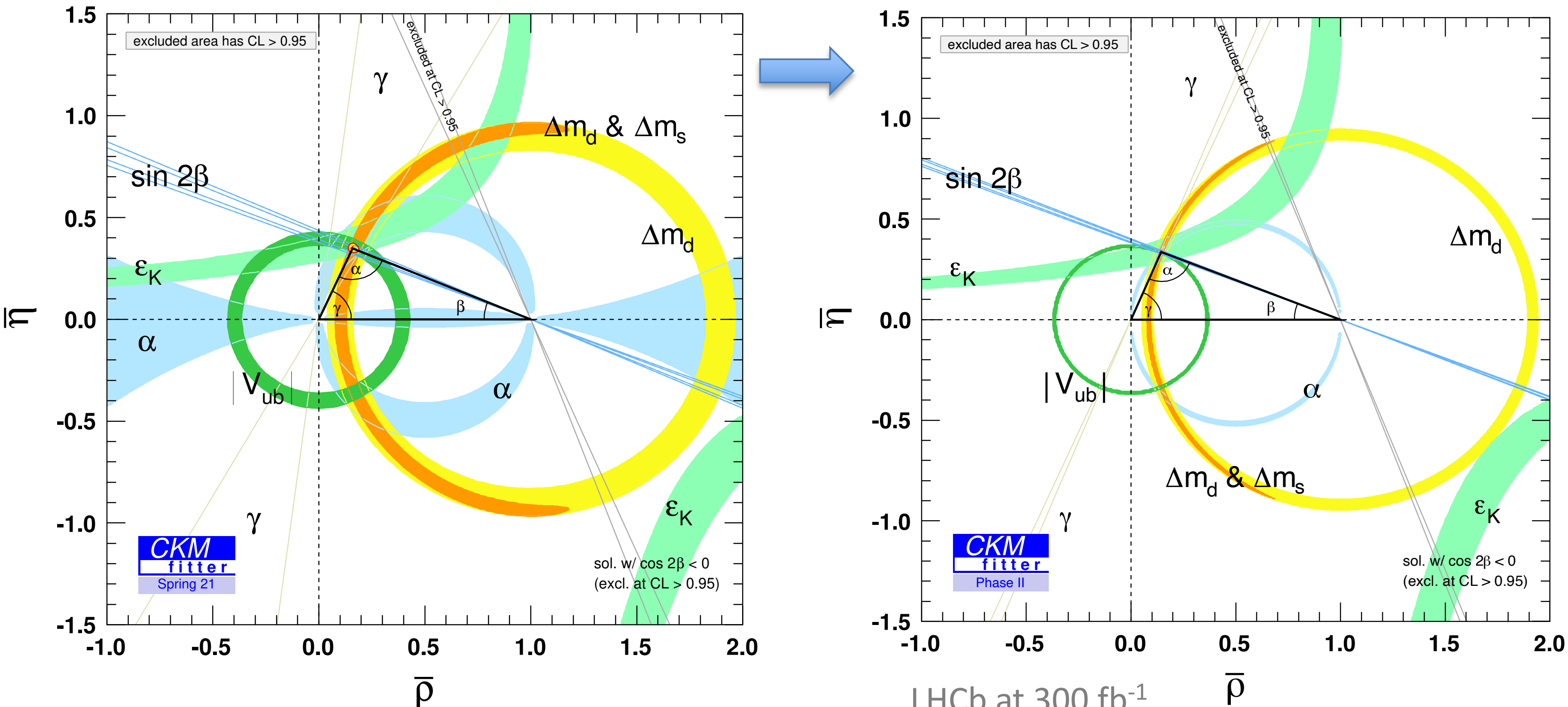


Snowmass 2013

$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{C_i}{\Lambda^2}\mathcal{O}_i$$

Indirect search for NP (cont.)

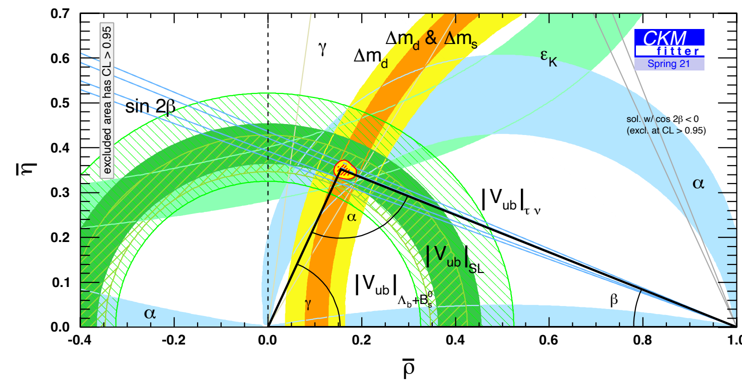
- Overconstrain the CKM triangle



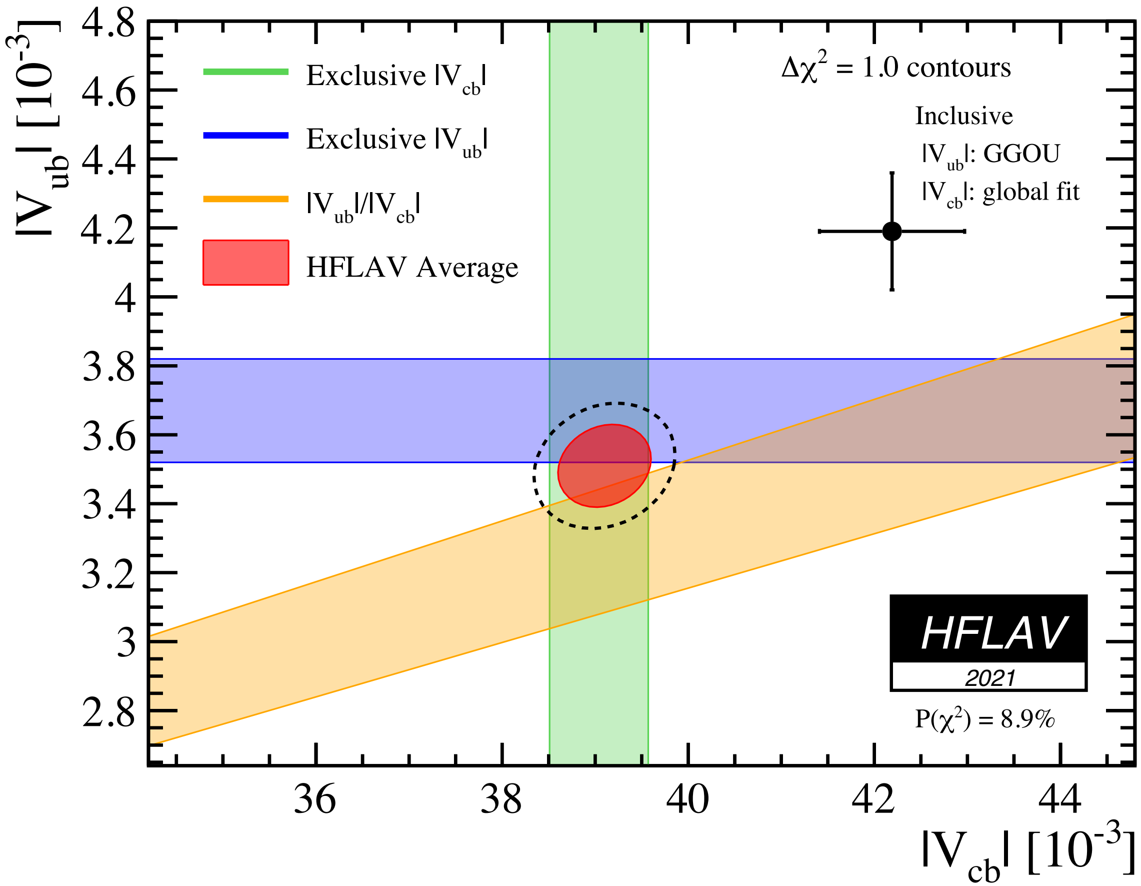
Please see talks of W. Qian, L. Sun, J. Yu

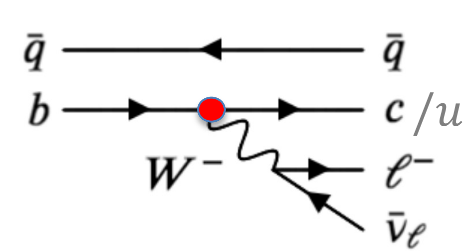
LHCb at 300 fb^{-1},
CMS/ATLAS at 3000 fb^{-1}, Belle II at 50 ab^{-1}.

V_{cb}, V_{ub}



- Some tension between exclusive/inclusive

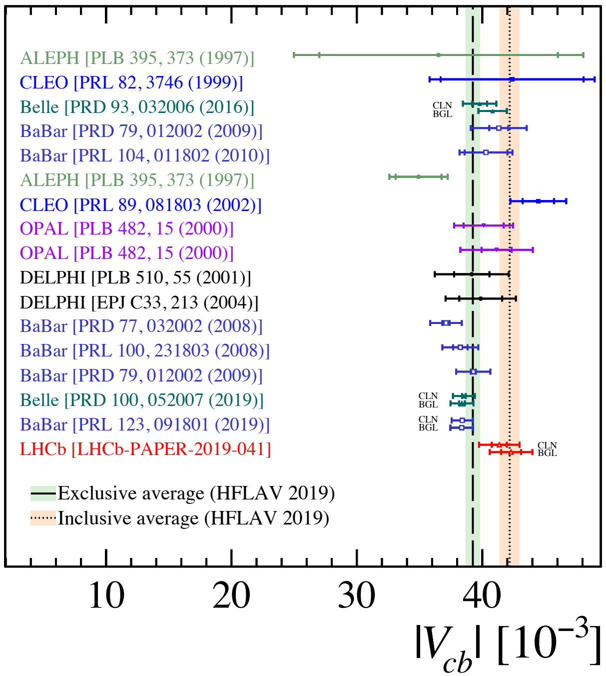


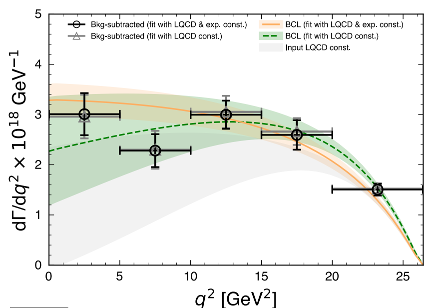


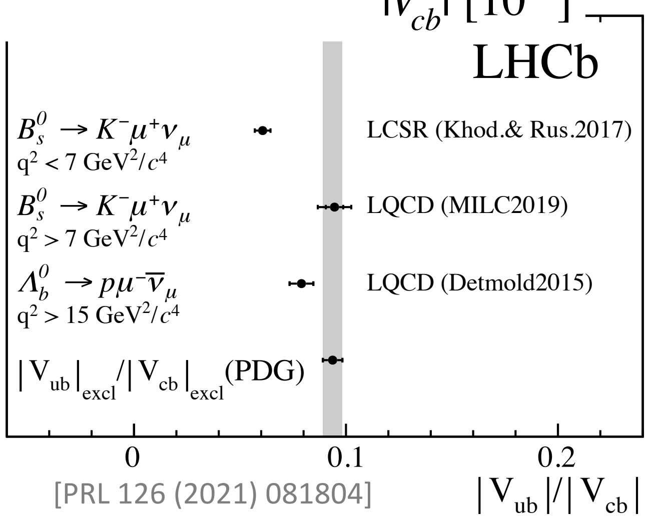
$$d\Gamma \propto |V_{cb}|^2 |f_H|^2$$

V_{cb}, V_{ub}

[PRD 101 (2020) 072004]

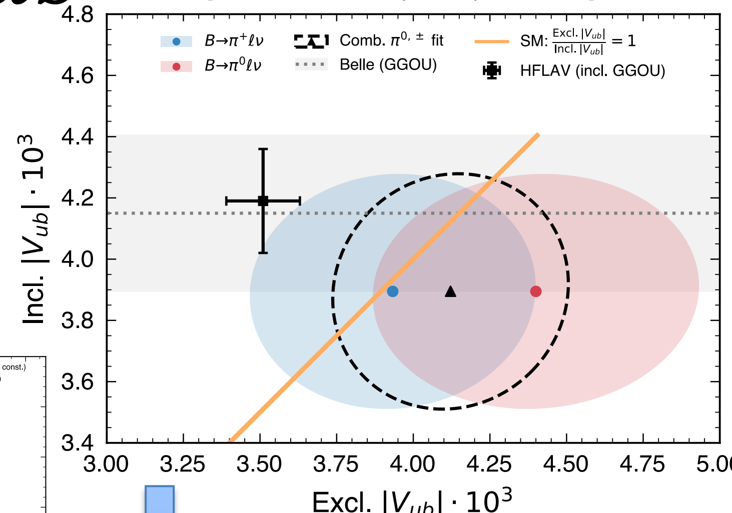






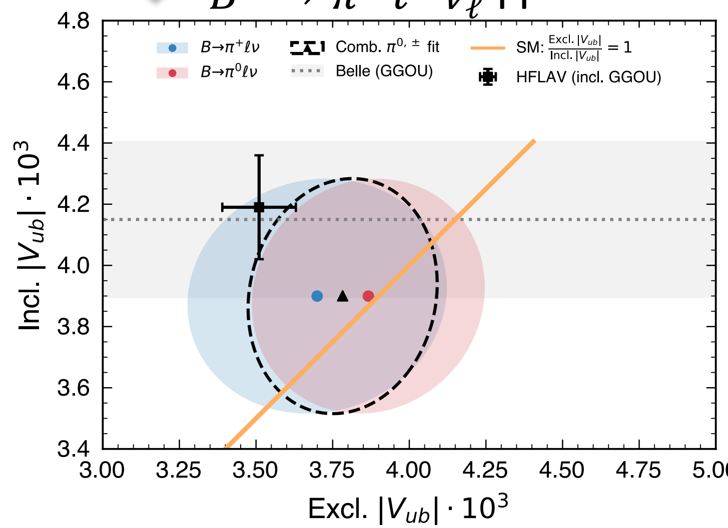
[PRL 126 (2021) 081804]

[Belle,PRL 131 (2023) 211801]



+

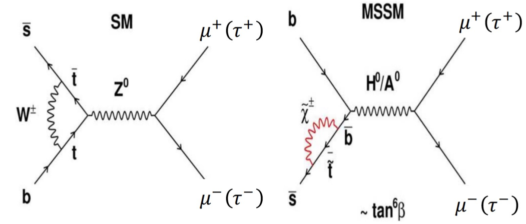
w/ exp constraint for $\bar{B}^0 \to \pi^+\ell^-\bar{\nu}_\ell$ FF

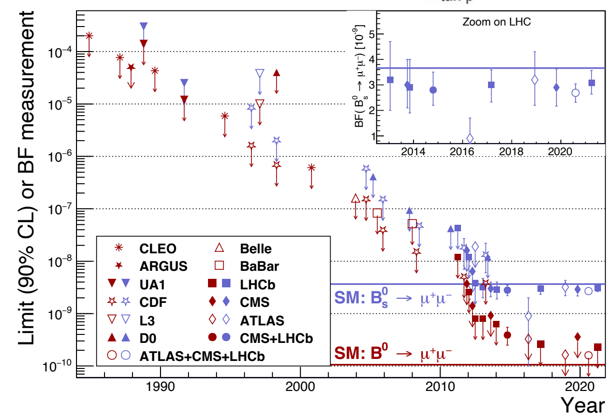


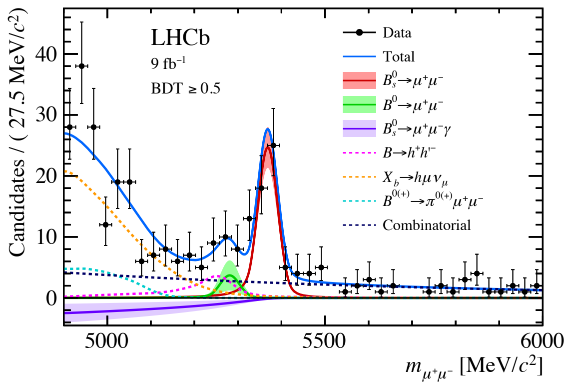
$B^0_{(s)} \to \mu^+\mu^-$

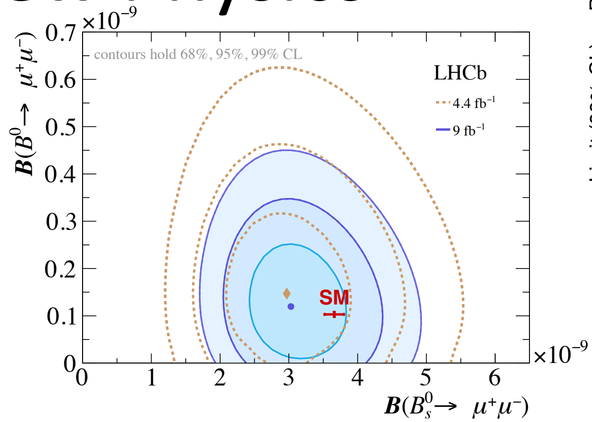
- Suppressed in SM, could be enhanced by New Physics

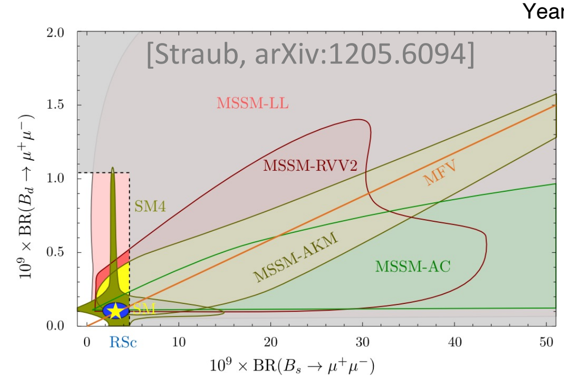
[PRL 128 (2022) 041801]

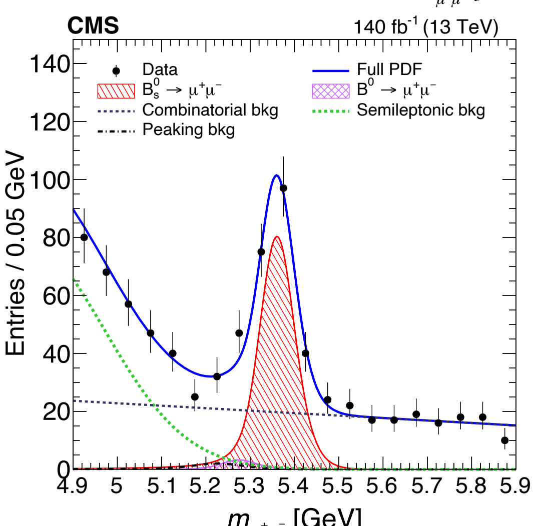


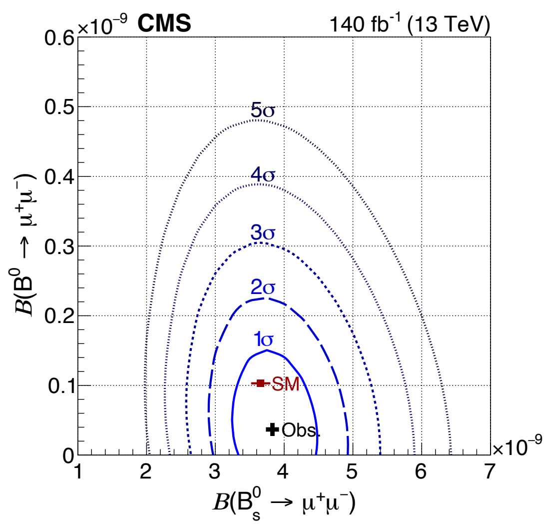


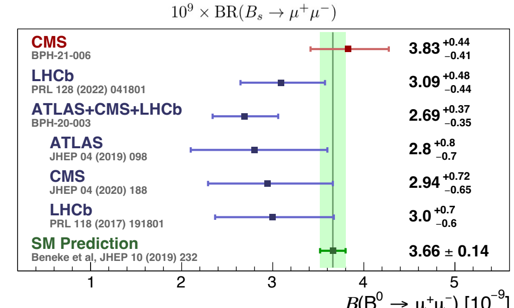












$B_s^0 \to \mu^+\mu^-$ eff. τ

- B_s^0 mixing $\Rightarrow$ effective τ

$$\tau_{\mu^+\mu^-} = \frac{\tau_{B_s}}{1-y_s^2}\left[\frac{1+2A_{\Delta\Gamma}^{\mu^+\mu^-}y_s+y_s^2}{1+A_{\Delta\Gamma}^{\mu^+\mu^-}y_s}\right]$$

$$A_{\Delta\Gamma}^{\mu^+\mu^-} \equiv \frac{R_H^{\mu^+\mu^-}-R_L^{\mu^+\mu^-}}{R_H^{\mu^+\mu^-}+R_L^{\mu^+\mu^-}}$$

$A_{\Delta\Gamma}$=1 in SM

$$y_s = \frac{\Delta\Gamma_s}{2\Gamma_s}$$

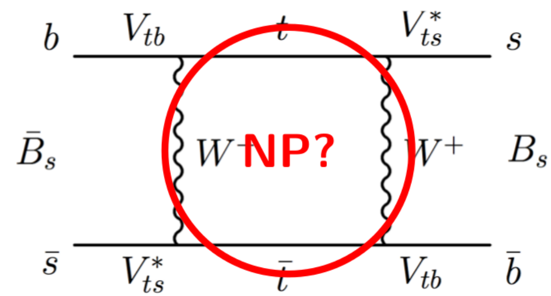
- Measured by LHCb, CMS, ALTAS, not-yet sensitive to $A_{\Delta\Gamma}$

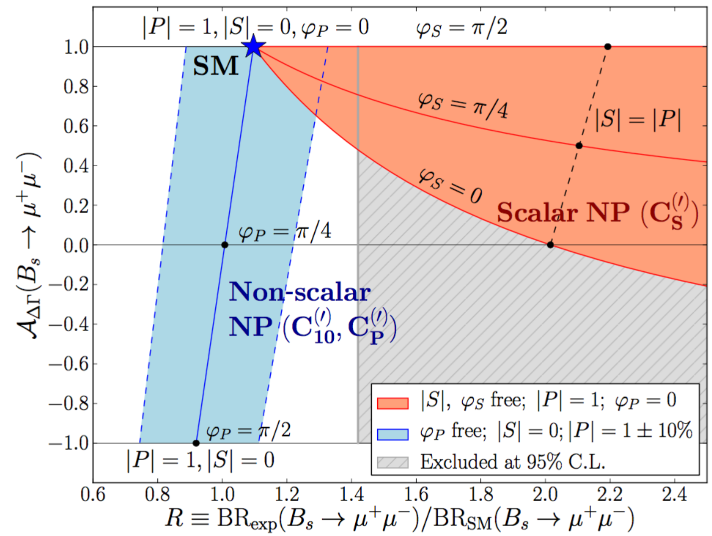
$\tau_{\mu\mu} = 2.07 \pm 0.29 \pm 0.03$ ps

$1.83^{+0.23}_{-0.20} \pm 0.04$ ps [CMS, PLB 842 (2023) 137955]

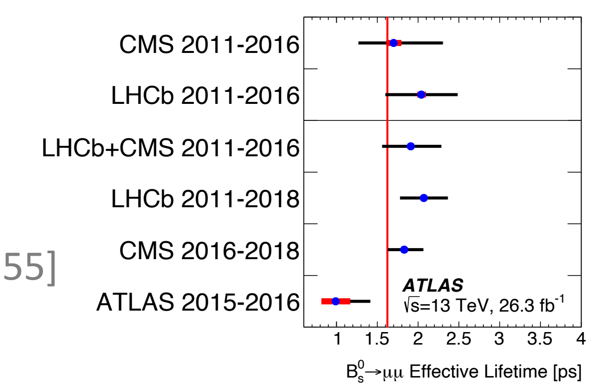
$0.99^{+0.42}_{-0.07} \pm 0.17$ ps [ATLAS, arXiv:2308.01171]

[PRL 128 (2022) 041801]

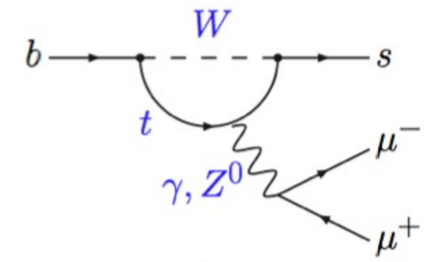




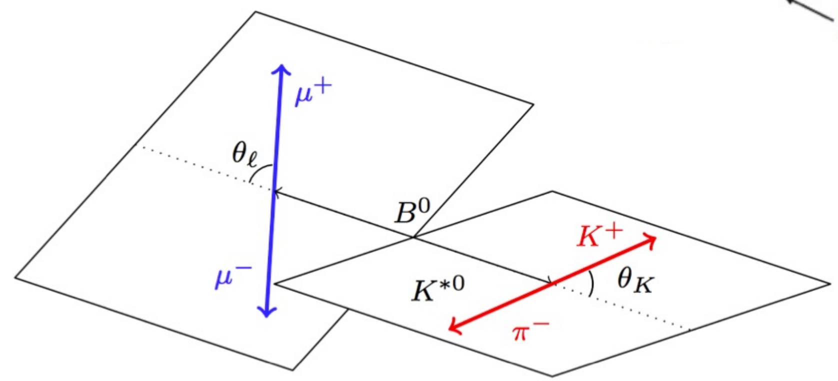
[De Bruyn *et al.*, PRL 109 (2012) 041801]



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



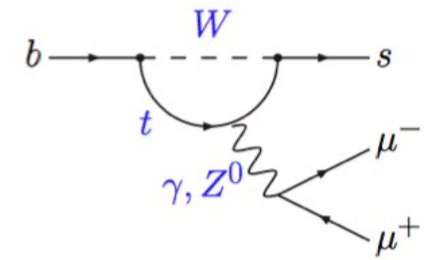
- Described by $q^2 = m^2(\ell^+\ell^-)$ and $\theta_\ell, \theta_K, \phi$
- Many observables!

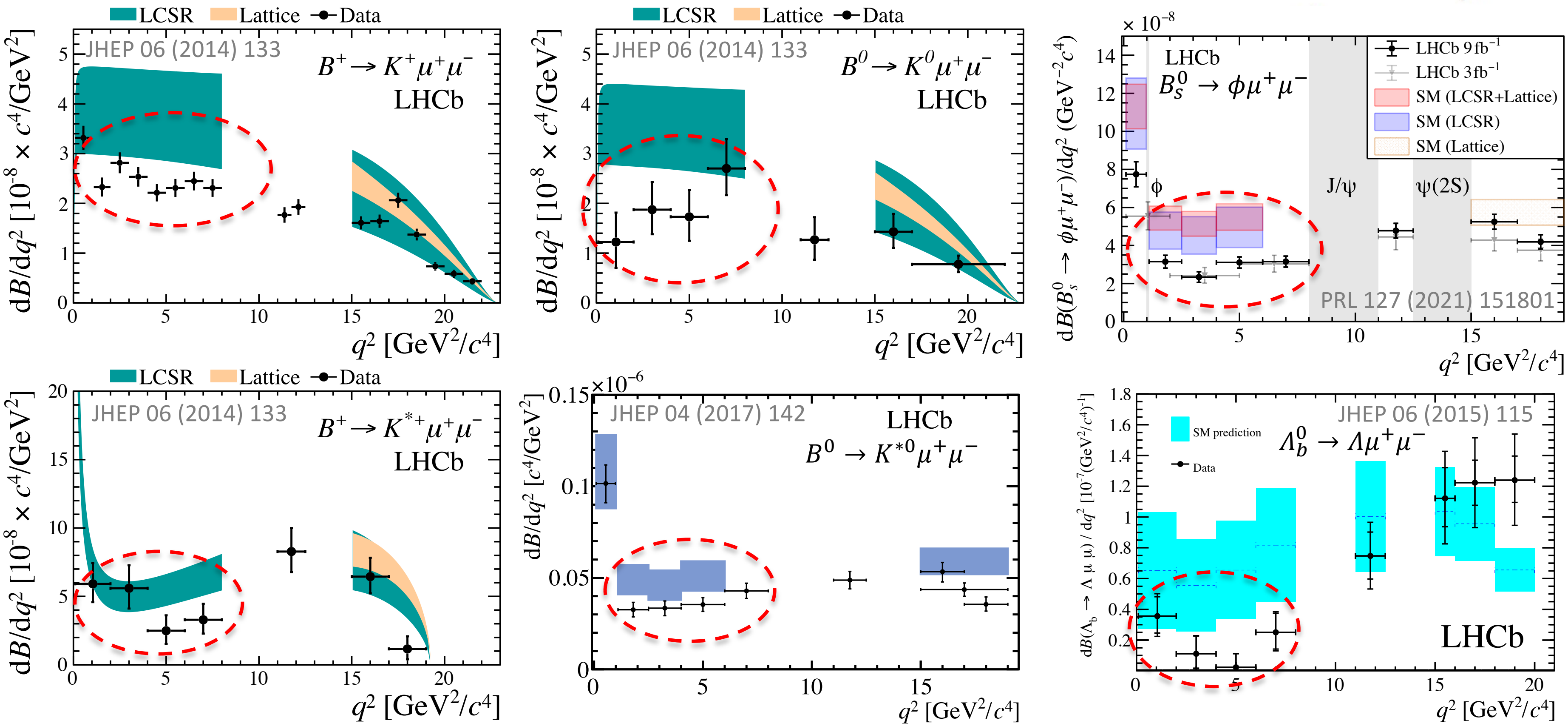


$$\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\vec{\Omega}} = \frac{9}{32\pi}\Big[\tfrac{3}{4}(1-F_\mathrm{L})\sin^2\theta_K + F_\mathrm{L}\cos^2\theta_K + \tfrac{1}{4}(1-F_\mathrm{L})\sin^2\theta_K\cos 2\theta_\ell$$
$$- F_\mathrm{L}\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi$$
$$+ S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi$$
$$+ \tfrac{4}{3}A_\mathrm{FB}\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi$$
$$+ S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]$$

Branching fraction of $b \to s\mu^+\mu^-$

- Pattern of tensions seen, theoretical uncertainty?

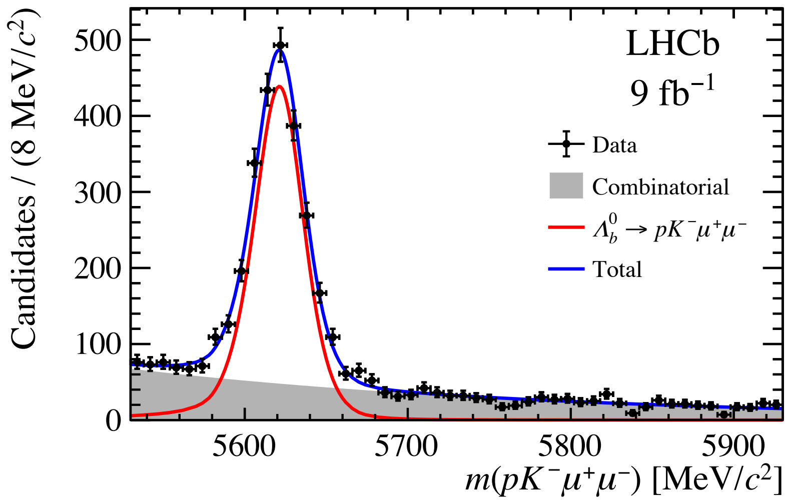


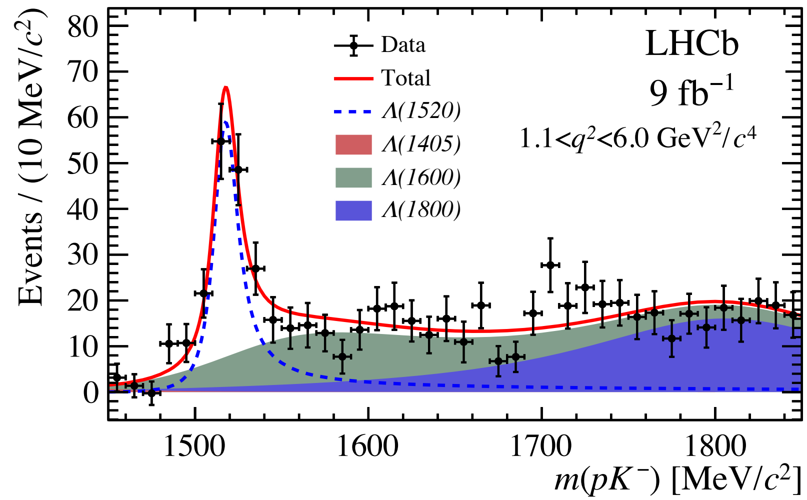


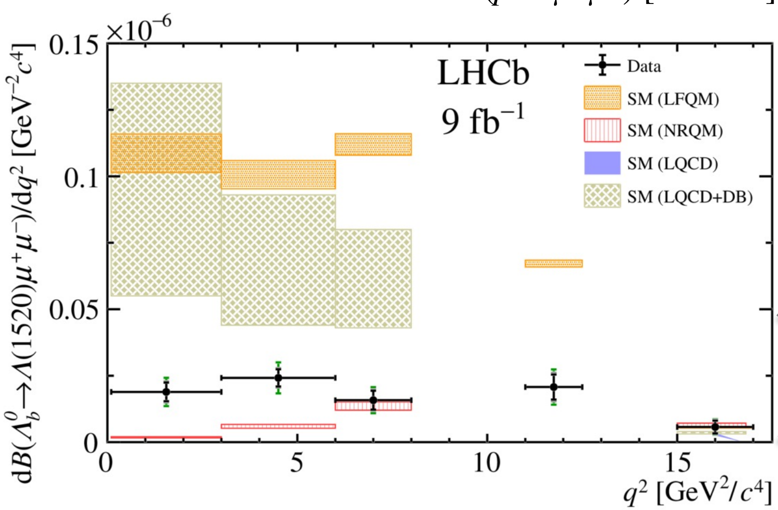
BR of $\Lambda_b^0 \to \Lambda(1520)\mu^+\mu^-$

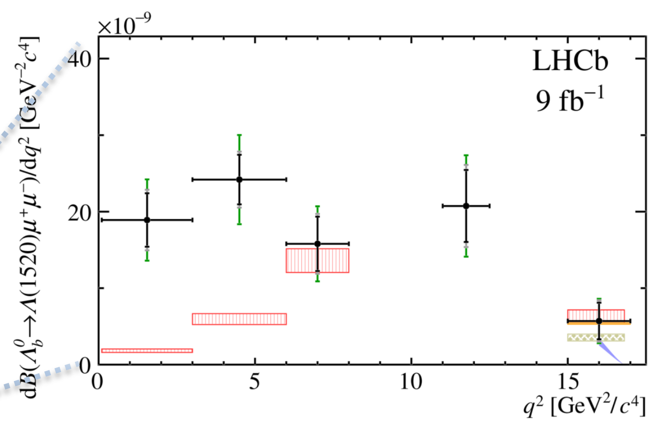
- First measurement w/ excited baryon, “milestone”

[PRL 131 (2023) 151801]



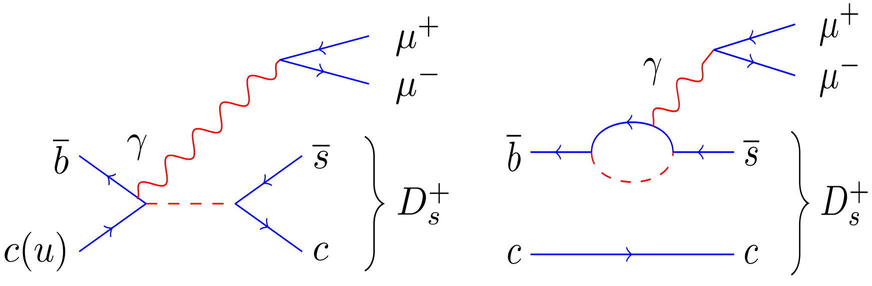






Search for $B \to D\mu^+\mu^-$

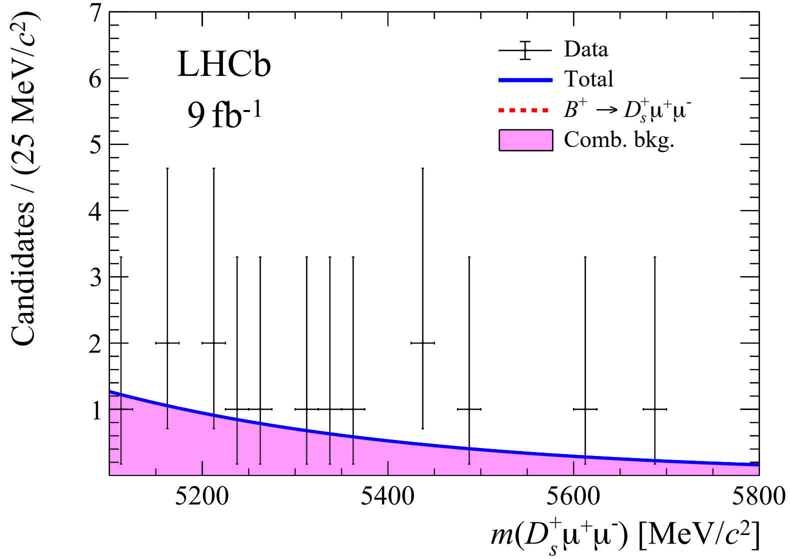
- Performed w/ all data, no signal yet
- Upper limits at 95% CL

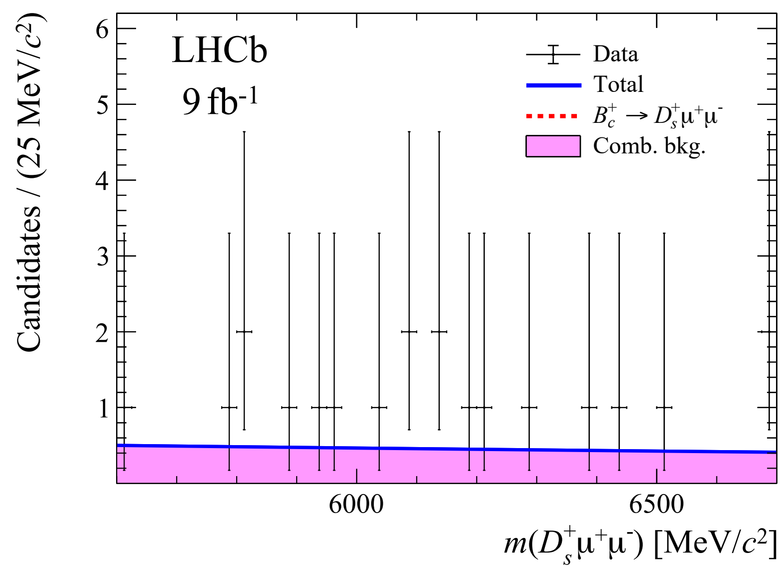


[arXiv:2308.06162]

$\mathcal{B}(B^+ \to D_s^+\mu^+\mu^-) < 3.2\times10^{-8}$

$\frac{f_c}{f_u} \cdot \mathcal{B}(B_c^+ \to D_s^+\mu^+\mu^-) < 9.6\times10^{-8}$





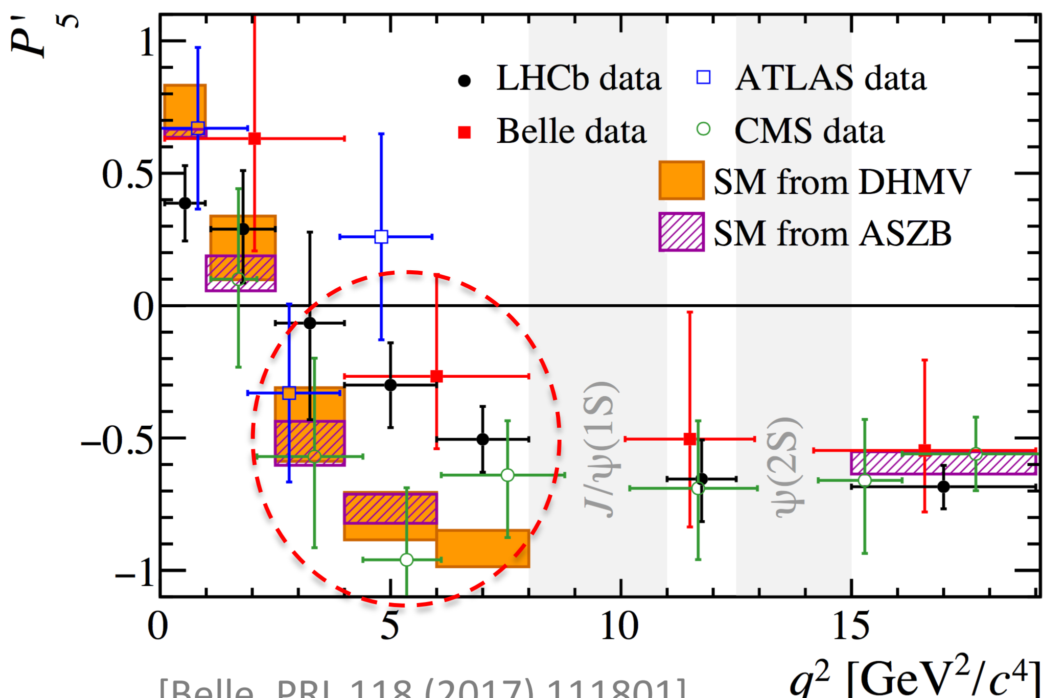
P'_5 with $B^0 \to K^{*0}\mu^+\mu^-$

- $P'_5 = \frac{S_5}{\sqrt{F_L(1-F_L)}}$, less form-factor dependent

[S. Descotes-Genon, *et al.*, JHEP 01 (2013) 048]

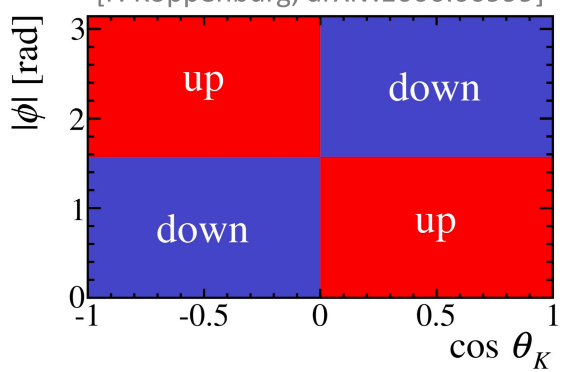
- Also measured by Belle, ATLAS, CMS

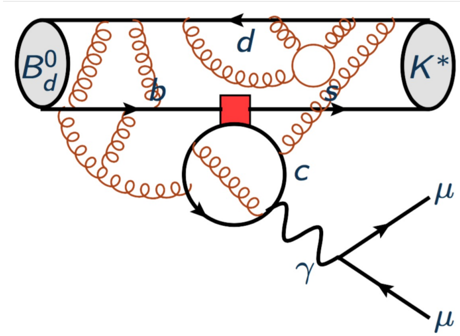
[PRL 125 (2020) 011802]



[Belle, PRL 118 (2017) 111801]
[ATLAS, JHEP 10 (2018) 047]
[CMS, PLB 781 (2018) 517]

Count blue minus red
[P. Koppenburg, arXiv:1606.00999]





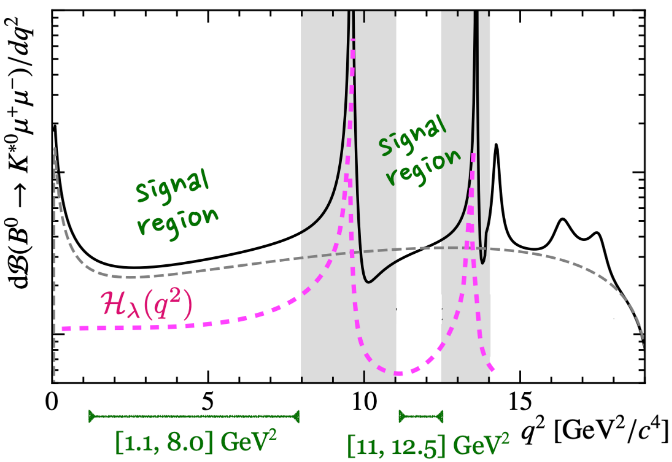
Amplitude analysis of $B^0 \to K^{*0}\mu^+\mu^-$

[LHCb-Paper-2023-033, in preparation]

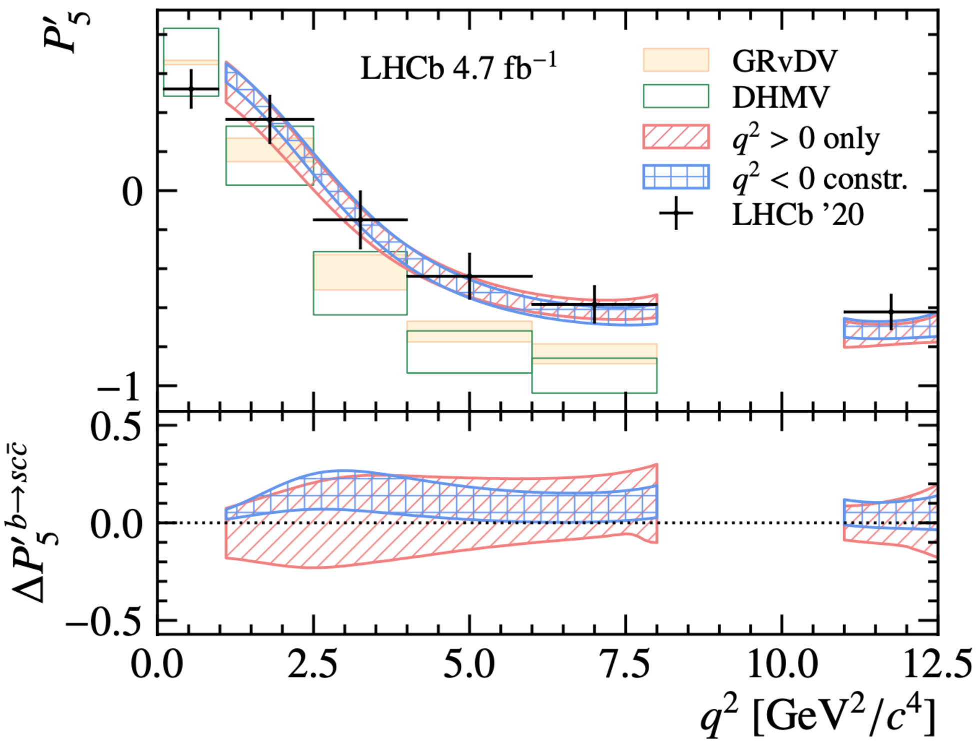
- Parametrise the decay amplitudes, choices of parametrisation introduce model-dependence

$$\mathcal{A}_\lambda^{L,R} = \mathcal{N}\left\{\left[(\mathcal{C}_9 \pm \mathcal{C}_9') \mp (\mathcal{C}_{10} \pm \mathcal{C}_{10}')\right]\mathcal{F}_\lambda(q^2,k^2) + \frac{2m_b M_B}{q^2}\left[(\mathcal{C}_7 \pm \mathcal{C}_7')\mathcal{F}_\lambda^T(q^2,k^2) - 16\pi^2\frac{M_B}{m_b}\mathcal{H}_\lambda(q^2,k^2)\right]\right\}$$

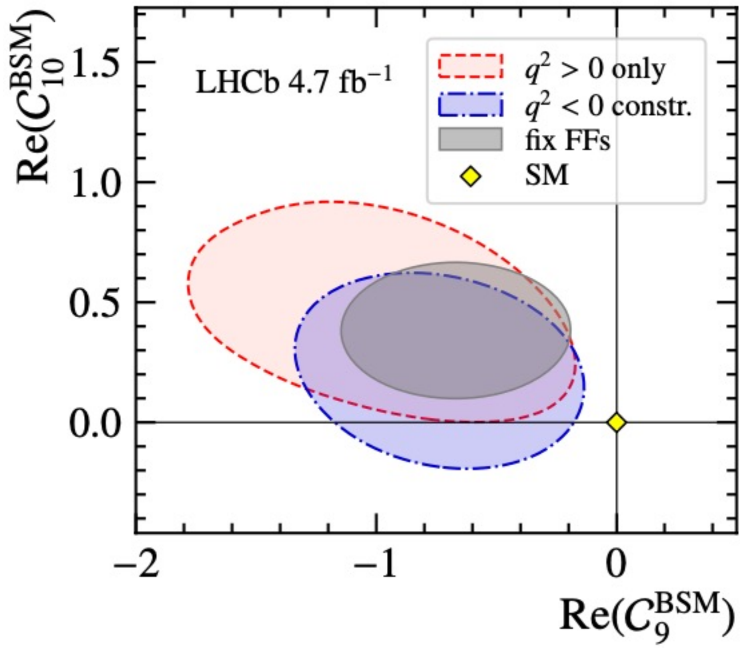
  – $\mathcal{C}_9^{(\prime)}, \mathcal{C}_{10}^{(\prime)}$ float, $\mathcal{C}_7^{(\prime)}$ fixed to SM
  – Local FF, constr. to LCSR+LQCD
  – Charm loop parameters $\mathcal{H}_\lambda$, constrained with
    - Exp. info of $B^0 \to \psi_n K^{*0}$ decays
    - Theo. predictions at $q^2 < 0$



[LHCb-Paper-2023-033, in preparation]



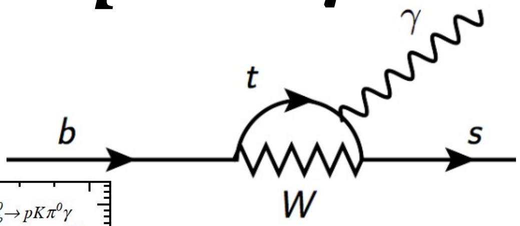
- Impact of charm loops consistent with predictions.



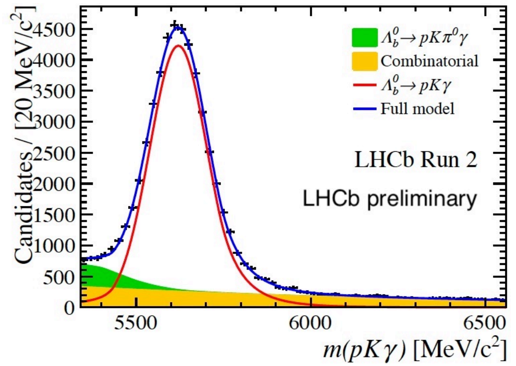
- With extra freedom given by $c\bar{c}$, a shift in $\mathcal{C}_9$ still prefered
- Compatibility with SM, 1.8σ in $\mathcal{C}_9$ and 1.4σ global

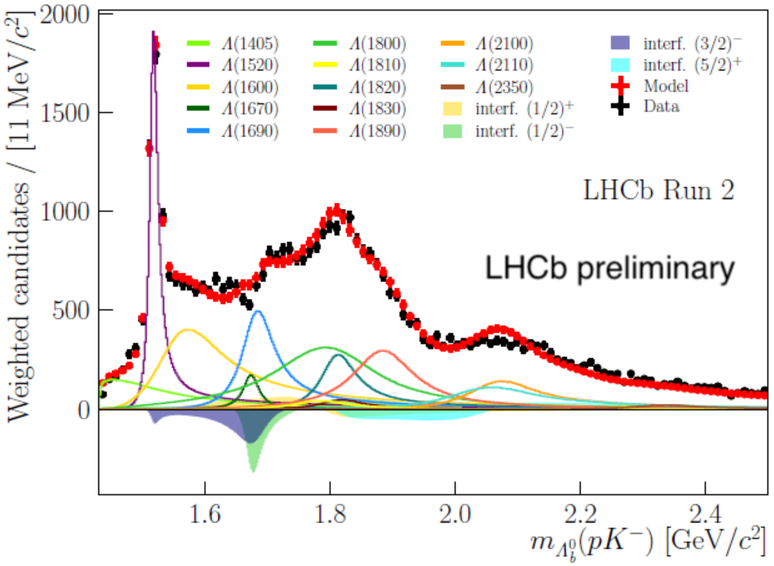
Amplitude analysis of $\Lambda_b^0 \to pK^-\gamma$

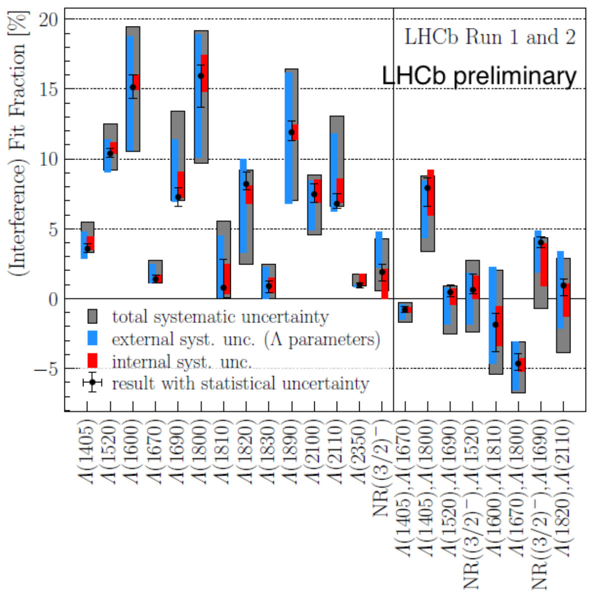
[LHCb-Paper-2023-036, in preparation]



- Contributions from many Λ^*, dominated by $\Lambda(1520), \Lambda(1600), \Lambda(1800), \Lambda(1890)$

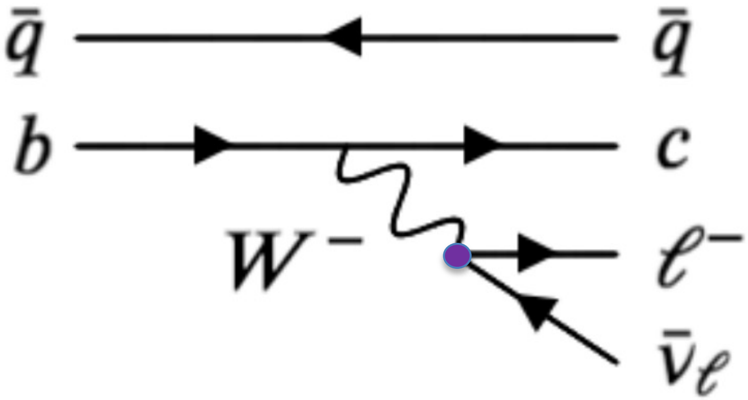


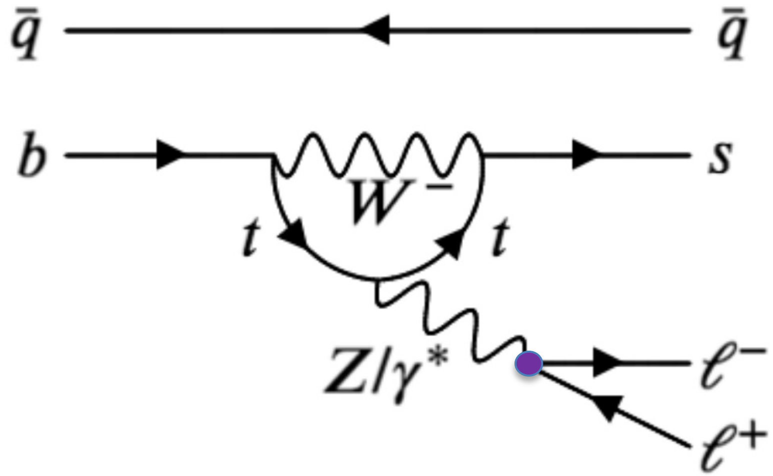




Lepton flavour universality

- In SM, three lepton families (e, μ, τ) have identical couplings to the gauge bosons





  - which means, e.g.,

$$R_K = \frac{\mathcal{B}(B^+ \to K^+ \mu^+ \mu^-)}{\mathcal{B}(B^+ \to K^+ e^+ e^-)} \cong 1$$

$\mathcal{O}(10^{-4})$ uncertainty
[C. Bobeth *et al.*, JHEP 12 (2007) 040]

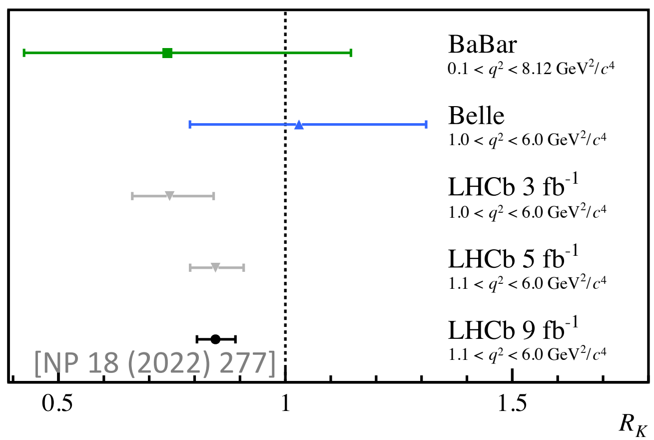
$\mathcal{O}(1\%)$ QED correction
[M. Bordone *et al.*, EJPC 76 (2016) 440]

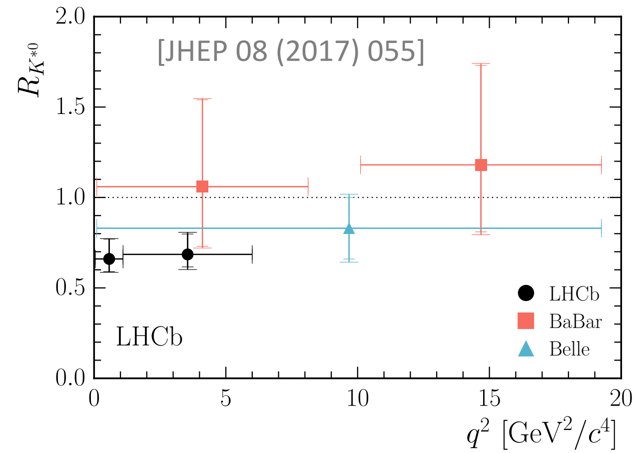
- Lepton flavour universality violation? New Physics!

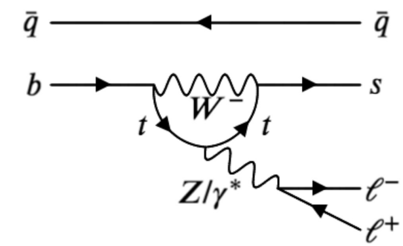
LFU in $b \to s\ell^+\ell^-$ decays

before Dec 2022

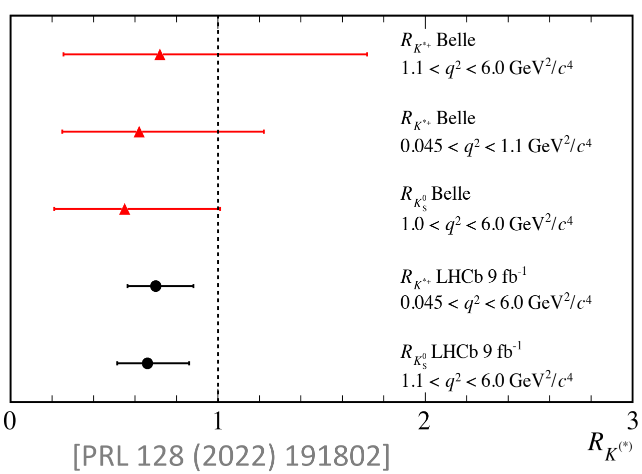
- Deviations from SM seen by LHCb

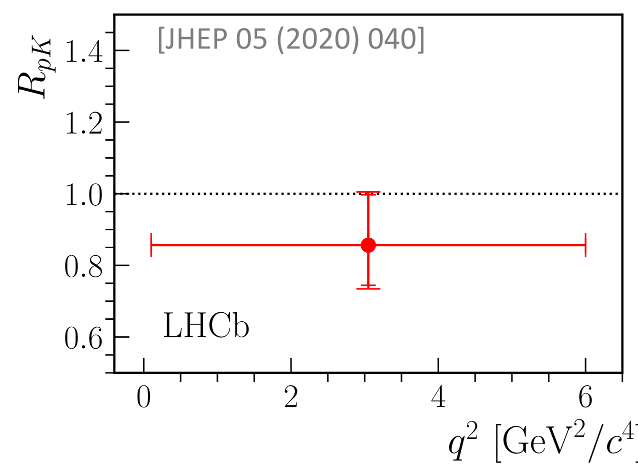


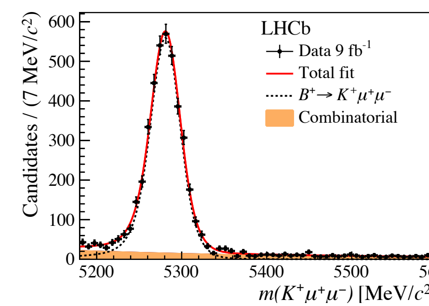


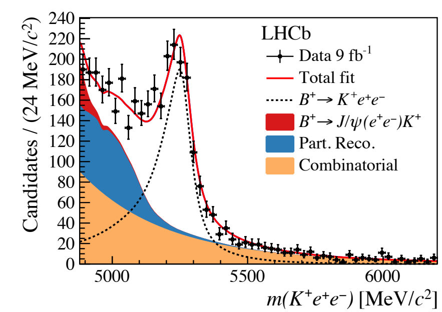


$$R_X = \frac{\mathcal{B}(H_b \to X\mu^+\mu^-)}{\mathcal{B}(H_b \to Xe^+e^-)}$$





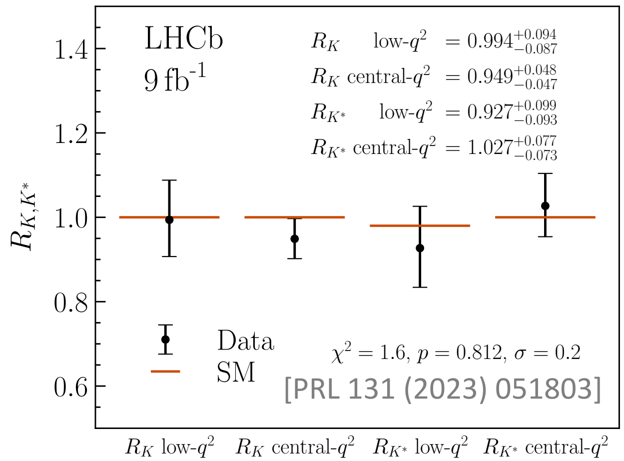


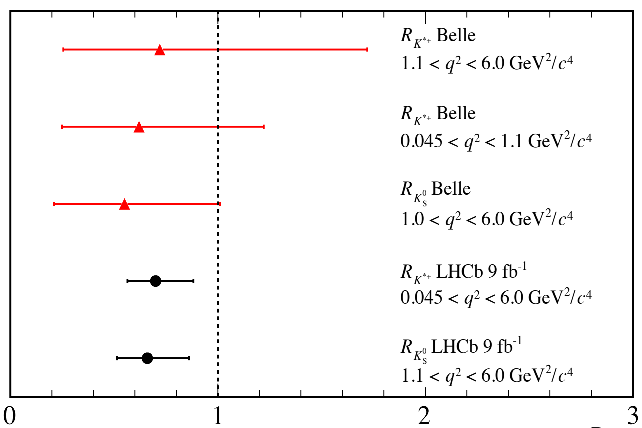


LFU in $b \to s\ell^+\ell^-$ decays

after Dec 2022

- Deviations mostly gone





[PRL 128 (2022) 191802]

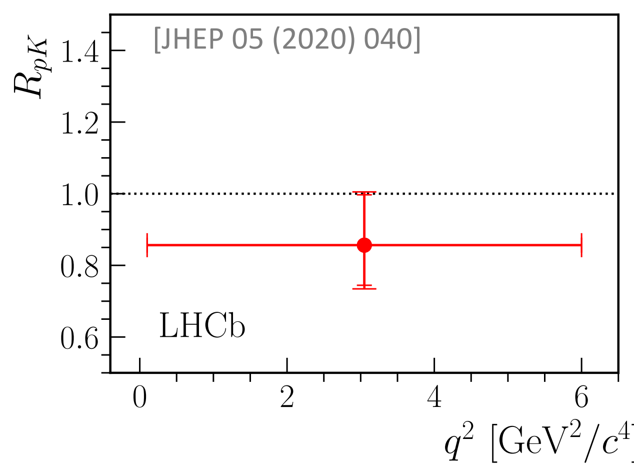
Precision at 5-10%

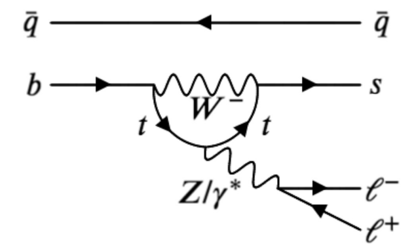
$\mathcal{O}(1\%)$ LFUV still possible

路漫漫其修远兮，吾将上下而求索

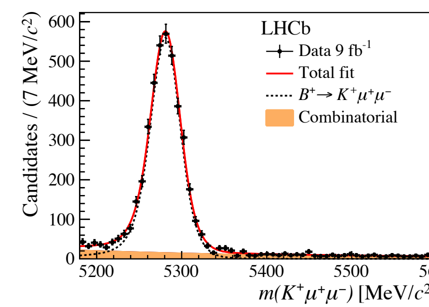
The road ahead will be long and our climb will be steep

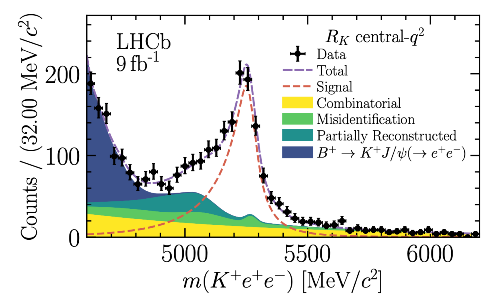
$$R_K = 0.78^{+0.46\ +0.09}_{-0.23\ -0.05}$$ [CMS, BPH-22-005-PAS]





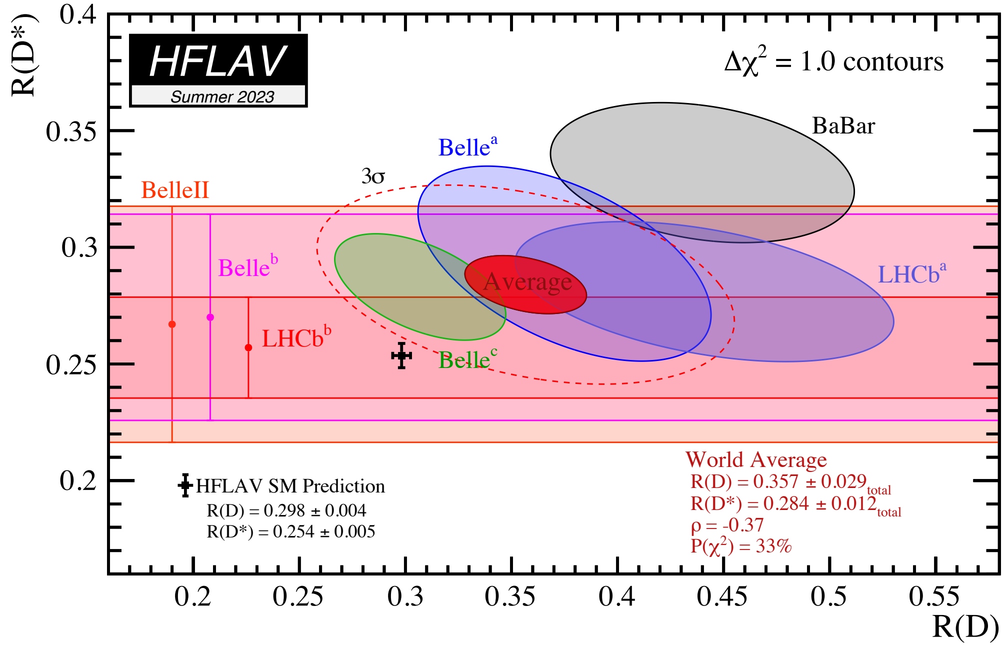
$$R_X = \frac{\mathcal{B}(H_b \to X\mu^+\mu^-)}{\mathcal{B}(H_b \to Xe^+e^-)}$$

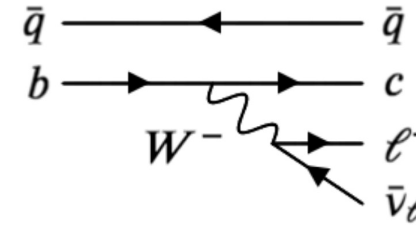




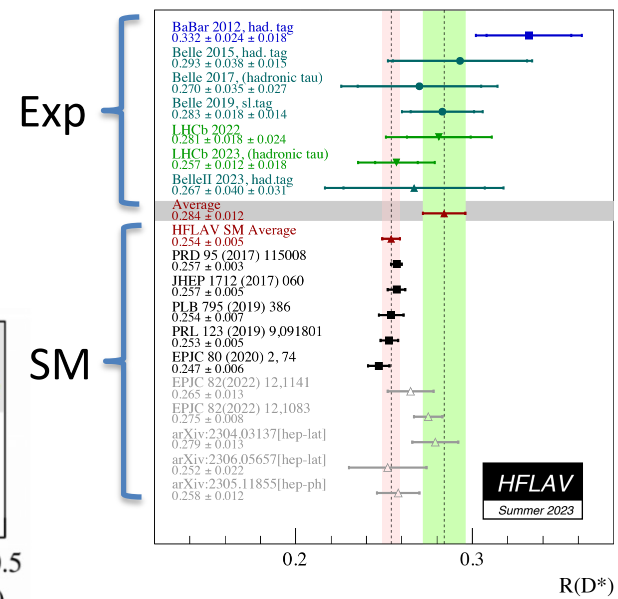
LFU in $b \to c\ell\nu$ decays

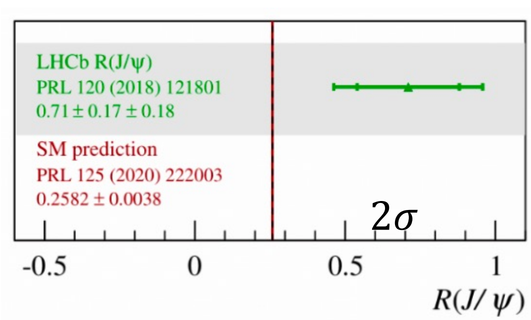
- Deviations from SM seen by Babar/Belle/LHCb

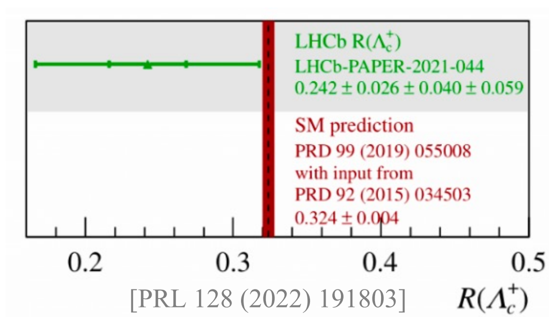




$$R(H_c) = \frac{\mathcal{B}(H_b \to H_c \tau^- \bar{\nu}_\tau)}{\mathcal{B}(H_b \to H_c \mu^- \bar{\nu}_\mu)}$$







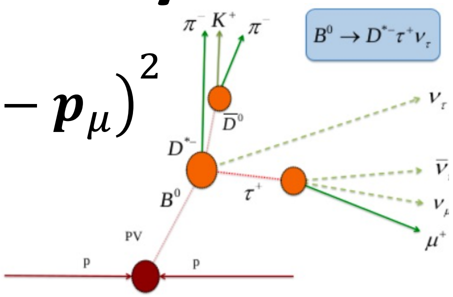
$R(D^{(*)})$ using muonic τ decays

- $\mathcal{B}(\tau \to \mu X)$~17.4%
- 3D fits
  - Signal yields: 44 000
  - Systematics: Simulation size, form factors, …

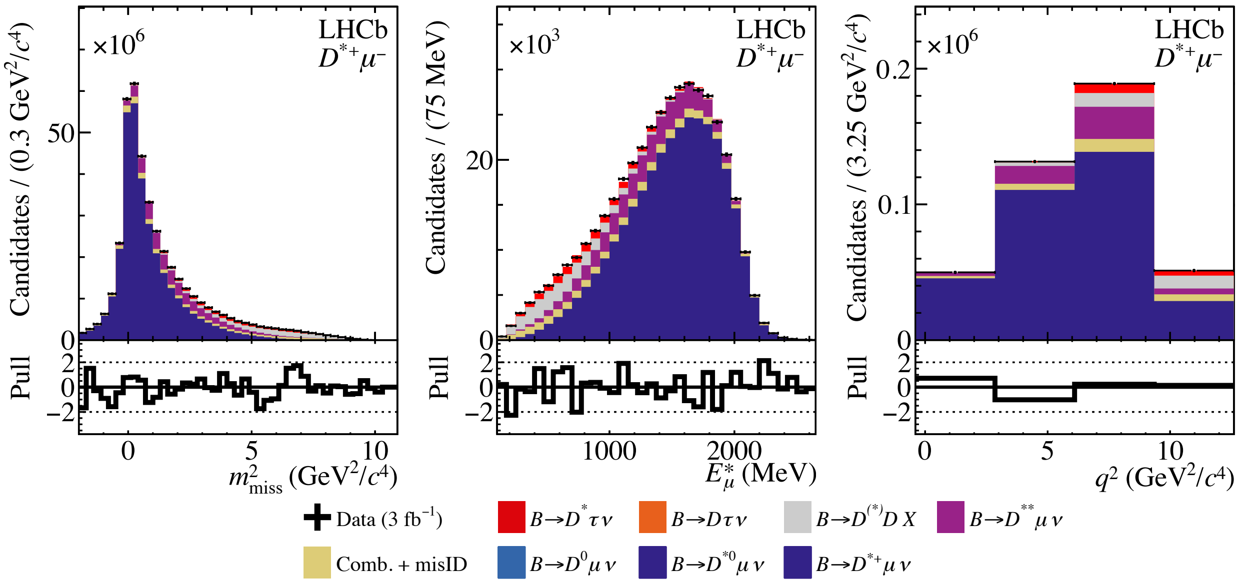
$m^2_{\rm miss} \equiv (\boldsymbol{p}_B^{\rm pRec} - \boldsymbol{p}_{D^{(*)}} - \boldsymbol{p}_\mu)^2$

E^*_μ, energy of μ

$q^2 = (\boldsymbol{p}_B^{\rm pRec} - \boldsymbol{p}_{D^{(*)}})^2$



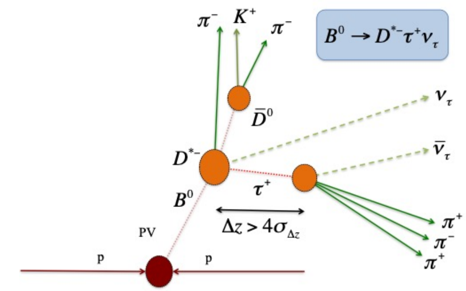
R(D*)=0.281 ± 0.018 ± 0.023



[PRL 131 (2023) 111802]

$R(D^*)$ using 3-prong τ decays

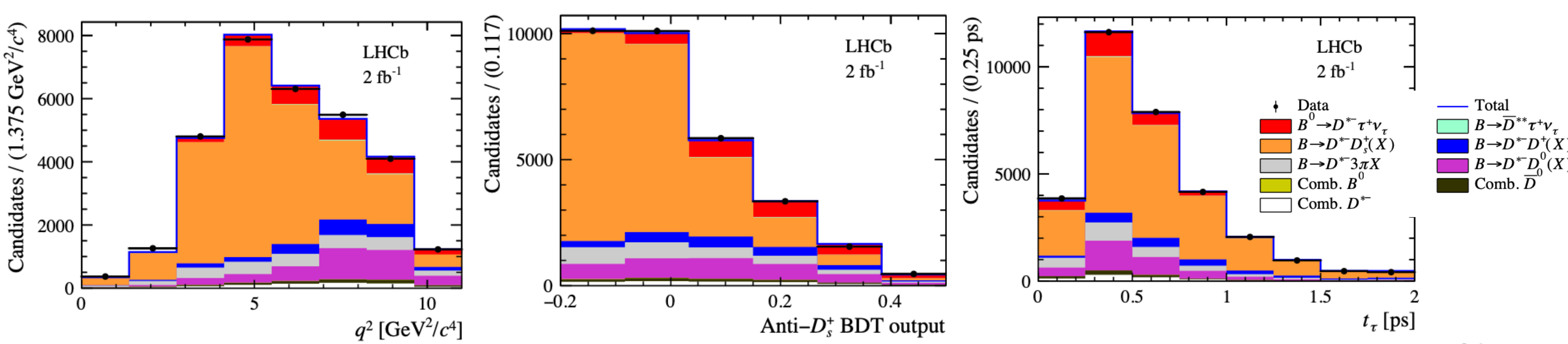
- $\mathcal{B}(\tau \to 3\pi^{\pm}X)$~9%+4%(≥1π⁰)
- Normalized to $B^0 \to D^{*-}3\pi$



$$R_{had}(D^*) = \frac{\mathcal{B}(B^0 \to D^{*-}\tau^+\nu_\tau)}{\mathcal{B}(B^0 \to D^{*-}\pi^+\pi^-\pi^+)} \quad R(D^*) = R_{had}(D^*) \times \frac{\mathcal{B}(B^0 \to D^{*-}\pi^+\pi^-\pi^+)}{\mathcal{B}(B^0 \to D^{*-}\mu^-\nu_\mu)}$$

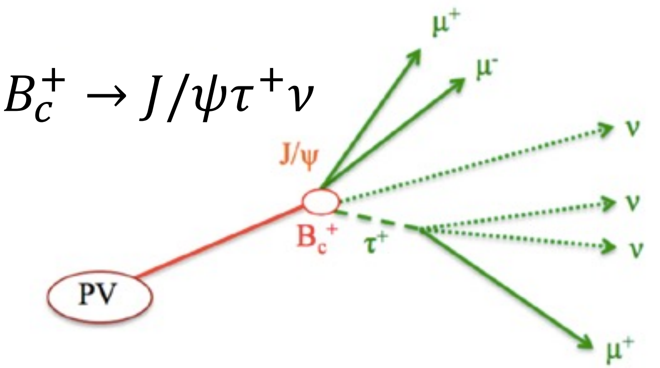
- 3D fits, R(D*)=0.247 ± 0.015 ± 0.015 ± 0.012
  - Signal yields: 2469 ± 154
  - Systematics: Simulation size, $D \to 3\pi X$ template, …

[PRD 108 (2023) 012018]



$R(J/\psi)$ using muonic τ decays

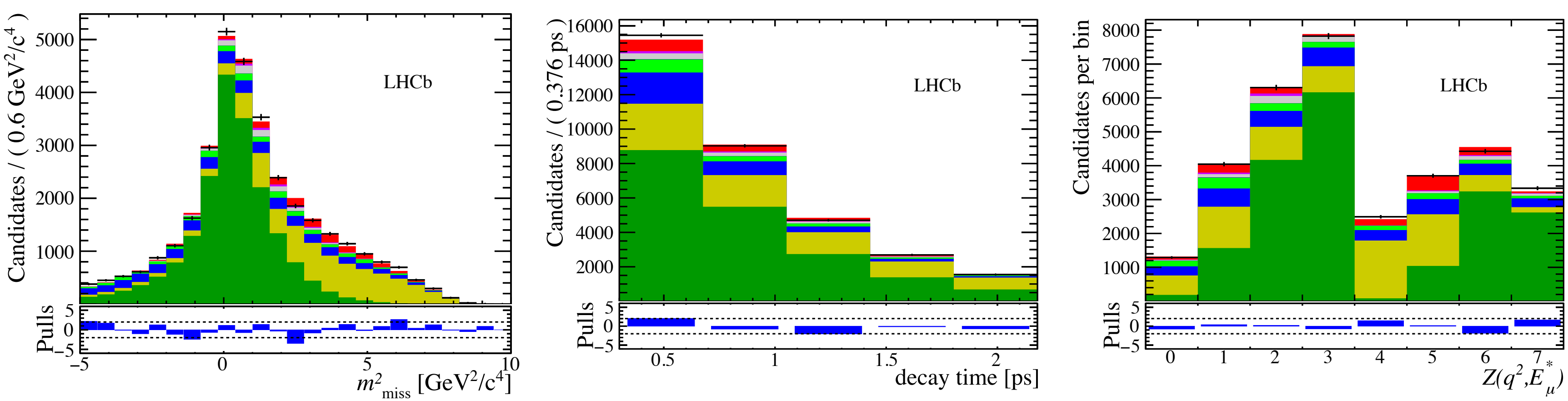
- Run-I, 1400 $\pm$ 300 signal (3σ) $B_c^+ \rightarrow J/\psi\tau^+\nu$
  - Pros: 3μ, $\mathcal{B}(\tau \rightarrow \mu X)$~17.4%
  - Cros: small $\sigma(B_c^+)$, no τ vertex



- $R(J/\psi) = 0.71 \pm 0.17 \pm 0.18$

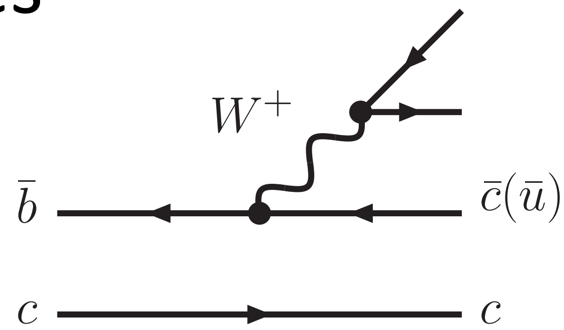
$$= 0.17^{+0.18}_{-0.17}{}^{+0.21}_{-0.22} \pm 0.19\,(\text{theo.})$$ [CMS, BPH-22-012-PAS]

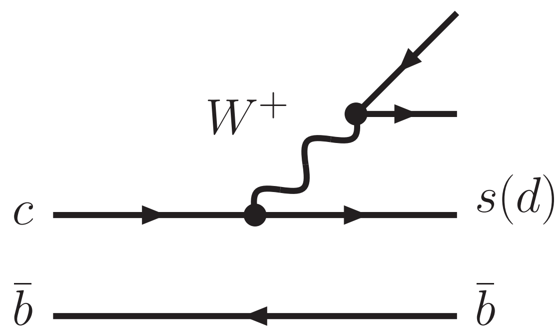
[PRL 120 (2018) 121801]

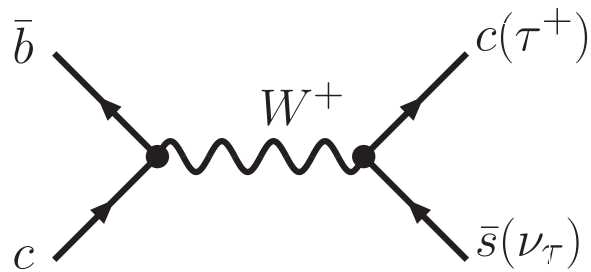


B_c^+ decays

- Three modes
  - $\bar{b} \rightarrow \bar{c}W^+$, $J/\psi \ell^+ \nu_\ell$
  - $c \rightarrow sW^+$, $B_s^0 \pi^+$
  - $c\bar{b} \rightarrow W^+$, $\tau^+ \nu_\tau$







B_c^+ $I(J^P) = 0(0^-)$ I, J, P need confirmation.

Quantum numbers shown are quark-model predictions.

B_c^+ MASS	6274.47 ± 0.32 MeV
$mB_c^+ - mB_s^0$	907.8 ± 0.5 MeV
B_c^+ MEAN LIFE	$(0.510 \pm 0.009) \times 10^{-12}$ s
POLARIZATION IN B_c^+ DECAY	
$\Gamma L/\Gamma$ in $B_c^+ \rightarrow J/\psi D_s^{*+}$	0.34 ± 0.09
$A_P(B_c^+)$	-0.010 ± 0.010

Decay Modes

Expand all decays

B_c^- modes are charge conjugates of the modes below.

Mode		Fraction (Γ_i / Γ)	Scale Factor/ Conf. Level	P(MeV/c)
Γ_1	$J/\psi(1S)\ell^+\nu_\ell$ anything	seen		
Γ_2	$J/\psi(1S)\mu^+\nu_\mu$	seen		2372
Γ_3	$J/\psi(1S)\tau^+\nu_\tau$	seen		1932
Γ_4	$J/\psi(1S)\pi^+$	seen		2370
Γ_5	$J/\psi(1S)K^+$	seen		2341
Γ_6	$J/\psi(1S)\pi^+\pi^+\pi^-$	seen		2350
Γ_7	$J/\psi(1S)K^+\pi^-\pi^+$			2294
Γ_8	$J/\psi(1S)K^+K^-K^+$			2073
Γ_9	$J/\psi(1S)a_1(1260)$	not seen		2169
Γ_{10}	$J/\psi(1S)K^+K^-\pi^+$	seen		2203
Γ_{11}	$J/\psi(1S)\pi^+\pi^+\pi^+\pi^-\pi^-$	seen		2309
Γ_{12}	$\psi(2S)\pi^+$	seen		2051
Γ_{13}	$\psi(2S)\pi^+\pi^-\pi^+$			2026
Γ_{14}	$\psi(2S)K^+K^-\pi^+$			1838
Γ_{15}	$J/\psi(1S)D^0K^+$	seen		1539
Γ_{16}	$J/\psi(1S)D^*(2007)^0K^+$	seen		1411
Γ_{17}	$J/\psi(1S)D^*(2010)^+K^{*0}$	seen		919
Γ_{18}	$J/\psi(1S)D^+K^{*0}$	seen		1122
Γ_{19}	$J/\psi(1S)D_s^+$	seen		1821
Γ_{20}	$J/\psi(1S)D_s^{*+}$	seen		1727
Γ_{21}	$J/\psi(1S)p\bar{p}\pi^+$	seen		1791
Γ_{22}	$\chi_{c0}\pi^+$	$(2.4^{+0.9}_{-0.8}) \times 10^{-5}$		2205
Γ_{23}	$p\bar{p}\pi^+$	not seen		2970
Γ_{24}	D^0K^+	seen		2837
Γ_{25}	$D^0\pi^+$	not seen		2858
Γ_{26}	$D^{*0}\pi^+$	not seen		2814
Γ_{27}	$D^{*0}K^+$	not seen		2792
Γ_{28}	$D_s^+\bar{D}^0$	$< 7.2 \times 10^{-4}$	CL=90%	2483
Γ_{29}	$D_s^+D^0$	$< 3.0 \times 10^{-4}$	CL=90%	2483
Γ_{30}	$D^+\bar{D}^0$	$< 1.9 \times 10^{-4}$	CL=90%	2521
Γ_{31}	D^+D^0	$< 1.4 \times 10^{-4}$	CL=90%	2521
Γ_{32}	$D_s^{*+}\bar{D}^0$	$< 5.3 \times 10^{-4}$	CL=90%	2425
Γ_{33}	$D_s^+\bar{D}^*(2007)^0$	$< 4.6 \times 10^{-4}$	CL=90%	2427
Γ_{34}	$D_s^{*+}D^0$	$< 9 \times 10^{-4}$	CL=90%	2425
Γ_{35}	$D_s^+D^*(2007)^0$	$< 6.6 \times 10^{-4}$	CL=90%	2427
Γ_{36}	$D^*(2010)^+\bar{D}^0$	$< 3.8 \times 10^{-4}$	CL=90%	2467
Γ_{37}	$D^*(2010)^+\bar{D}^0$, $D^{*+} \rightarrow D^+\pi^0 / \gamma$	not seen		
Γ_{38}	$D^+\bar{D}^*(2007)^0$	$< 6.5 \times 10^{-4}$	CL=90%	2466
Γ_{39}	$D^*(2007)^+D^0$	$< 2.0 \times 10^{-4}$	CL=90%	
Γ_{40}	$D^*(2010)^+D^0$, $D^{*+} \rightarrow D^+\pi^0 / \gamma$	not seen		2467

UROP

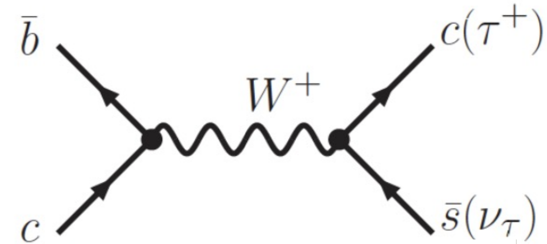
$\mathcal{B}(B_c^+ \to B_s^0 \pi^+)$

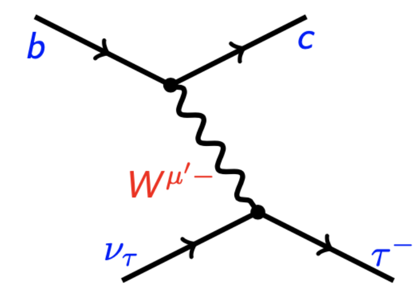
- Measured w/ Run2 data, helps constrain $\Gamma(b \to c\tau\nu)$

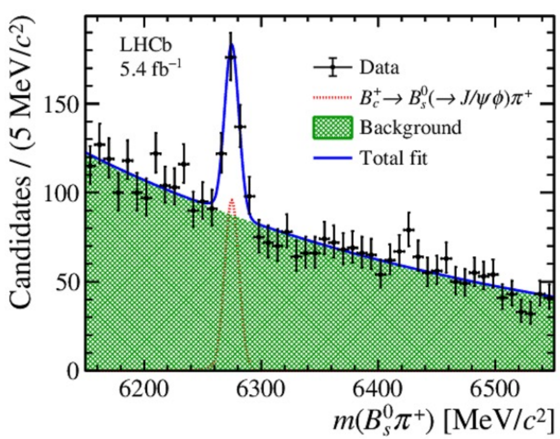
$$\frac{\mathcal{B}(B_c^+ \to B_s^0 \pi^+)}{\mathcal{B}(B_c^+ \to J/\psi \pi^+)} = 91 \pm 13$$

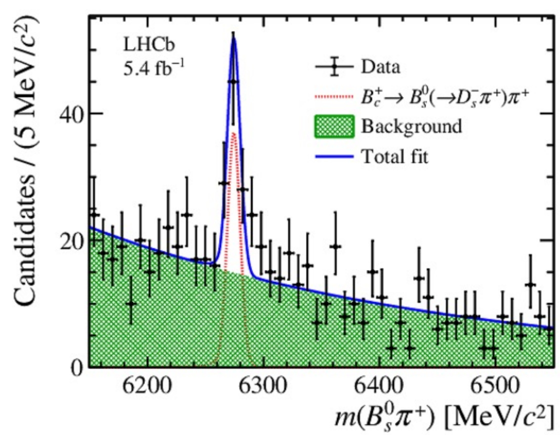
$\Longrightarrow \mathcal{B}(B_c^+ \to B_s^0 \pi^+)$ is 8% - 30% depending on $\mathcal{B}(B_c^+ \to J/\psi \pi^+)$

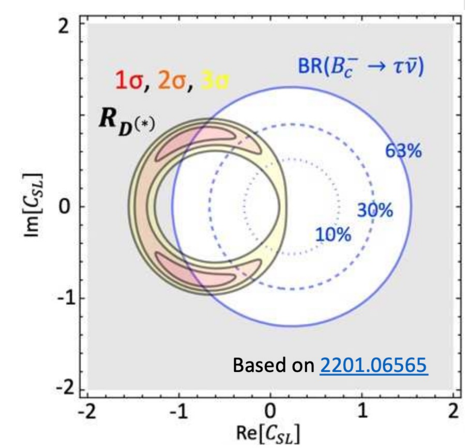
[JHEP 07 (2023) 066]









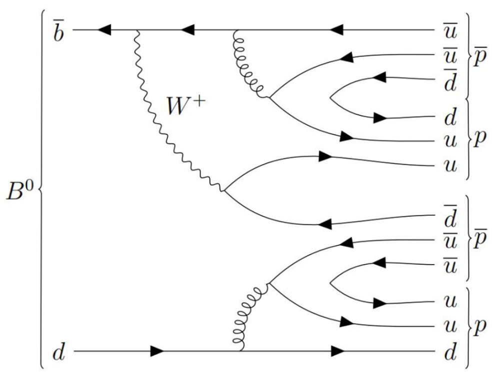


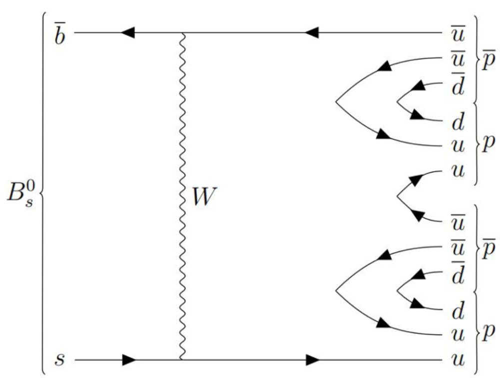
Credit: R. Watanabe

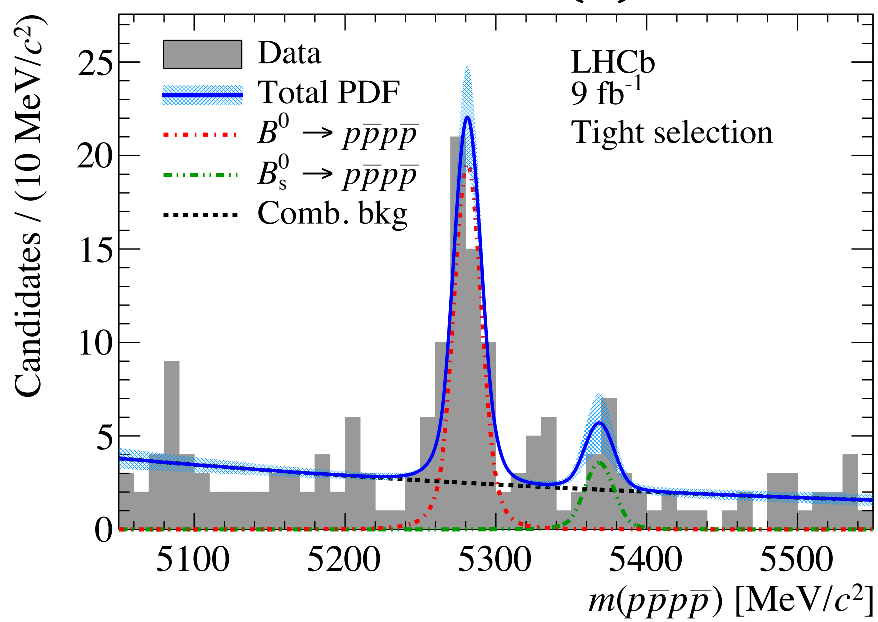
Search for $B^0_{(s)} \to pp\bar{p}\bar{p}$

- Non-pert. + weak, threshold enhancement?
- First observation (evidence) of $B^0_{(s)} \to pp\bar{p}\bar{p}$

[PRL 131 (2023) 091901]





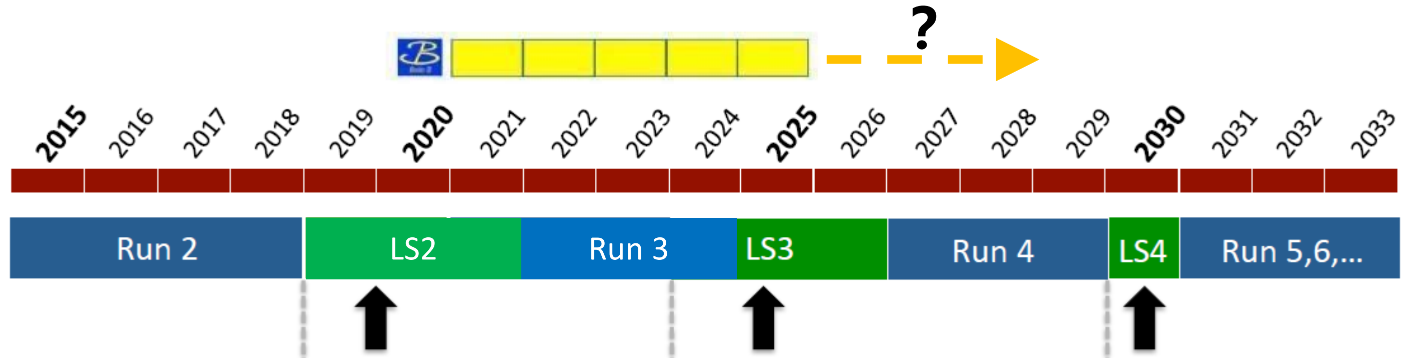


$\mathcal{B}(B^0 \to p\bar{p}p\bar{p}) = (2.2 \pm 0.4 \pm 0.1 \pm 0.1) \times 10^{-8}$

$\mathcal{B}(B^0_s \to p\bar{p}p\bar{p}) = (2.3 \pm 1.0 \pm 0.2 \pm 0.1) \times 10^{-8}$

$B^0_s \to p\bar{p}p\bar{p}$ higher than $\left|\frac{V_{us}}{V_{ud}}\right|^2 \sim 5\%$?

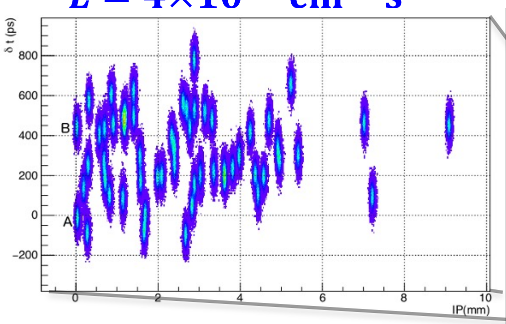
The LHCb upgrades

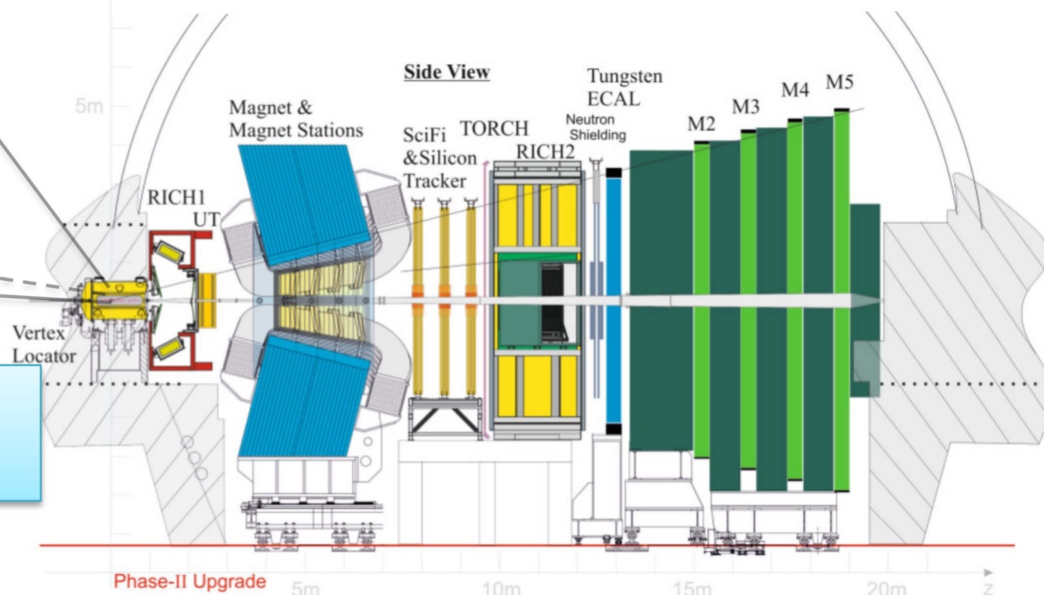


9 fb^{-1} — $L = 4\times10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

50 fb^{-1} — $L = 2\times10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

300 fb^{-1} — $L = 2\times10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$





Upgrade II, 4D detector Timing, $\mathcal{O}(10\ \mathrm{ps})$, is essential

Please see Z. Yang's talk

[CERN-LHCC-2018-027, 2021-012]

Prospects

- LHCb upgrades
  (2025: 23 fb^{-1}, Upgrade-II: 300 fb^{-1})

[CERN-LHCC-2018-027, 2021-012]

Observable	Current LHCb	LHCb 2025	Belle II	Upgrade II	ATLAS & CMS
EW Penguins					
R_K $(1 < q^2 < 6\,\mathrm{GeV}^2c^4)$	0.1 [274]	0.025	0.036	0.007	–
R_{K^*} $(1 < q^2 < 6\,\mathrm{GeV}^2c^4)$	0.1 [275]	0.031	0.032	0.008	–
R_ϕ, R_{pK}, R_π	–	0.08, 0.06, 0.18	–	0.02, 0.02, 0.05	–
CKM tests					
γ, with $B_s^0 \to D_s^+ K^-$	$(^{+17}_{-22})^\circ$ [136]	4°	–	1°	–
γ, all modes	$(^{+5.0}_{-5.8})^\circ$ [167]	1.5°	1.5°	0.35°	–
$\sin 2\beta$, with $B^0 \to J/\psi K_S^0$	0.04 [606]	0.011	0.005	0.003	–
ϕ_s, with $B_s^0 \to J/\psi \phi$	49 mrad [44]	14 mrad	–	4 mrad	22 mrad [607]
ϕ_s, with $B_s^0 \to D_s^+ D_s^-$	170 mrad [49]	35 mrad	–	9 mrad	–
$\phi_s^{s\bar{s}s}$, with $B_s^0 \to \phi\phi$	154 mrad [94]	39 mrad	–	11 mrad	Under study [608]
a_{sl}^s	33×10^{-4} [211]	10×10^{-4}	–	3×10^{-4}	–
$\lvert V_{ub}\rvert / \lvert V_{cb}\rvert$	6% [201]	3%	1%	1%	–
$\boldsymbol{B_s^0, B^0 \to \mu^+\mu^-}$					
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	90% [264]	34%	–	10%	21% [609]
$\tau_{B_s^0 \to \mu^+\mu^-}$	22% [264]	8%	–	2%	–
$S_{\mu\mu}$	–	–	–	0.2	–
$\boldsymbol{b \to c\ell^-\bar{\nu}_l}$ **LUV studies**					
$R(D^*)$	0.026 [215, 217]	0.0072	0.005	0.002	–
$R(J/\psi)$	0.24 [220]	0.071	–	0.02	–
Charm					
$\Delta A_{CP}(KK - \pi\pi)$	8.5×10^{-4} [610]	1.7×10^{-4}	5.4×10^{-4}	3.0×10^{-5}	–
A_Γ $(\approx x \sin\phi)$	2.8×10^{-4} [240]	4.3×10^{-5}	3.5×10^{-4}	1.0×10^{-5}	–
$x \sin\phi$ from $D^0 \to K^+\pi^-$	13×10^{-4} [228]	3.2×10^{-4}	4.6×10^{-4}	8.0×10^{-5}	–
$x \sin\phi$ from multibody decays	–	$(K3\pi)$ 4.0×10^{-5}	$(K_S^0\pi\pi)$ 1.2×10^{-4}	$(K3\pi)$ 8.0×10^{-6}	–

Summary

- Many interesting results from LHCb
  - Flavour anomalies, $V_{c/ub}$, $b \to s\mu^+\mu^-$ BR, $\mathcal{R}_{K^{(*0)}}$, $\mathcal{R}_{D^*}$, to be confirmed or refuted with more data
  - Rare decays, $B \to pp\bar{p}\bar{p}$
- With LHCb upgrade (50 fb^{-1}) & upgrade-II (300 fb^{-1}), much more will be done
- Your continued and strong supports are always appreciated!
  - Form factors, non-form-factor contributions
  - New observables?