LHCb实验测量对格点QCD的需求

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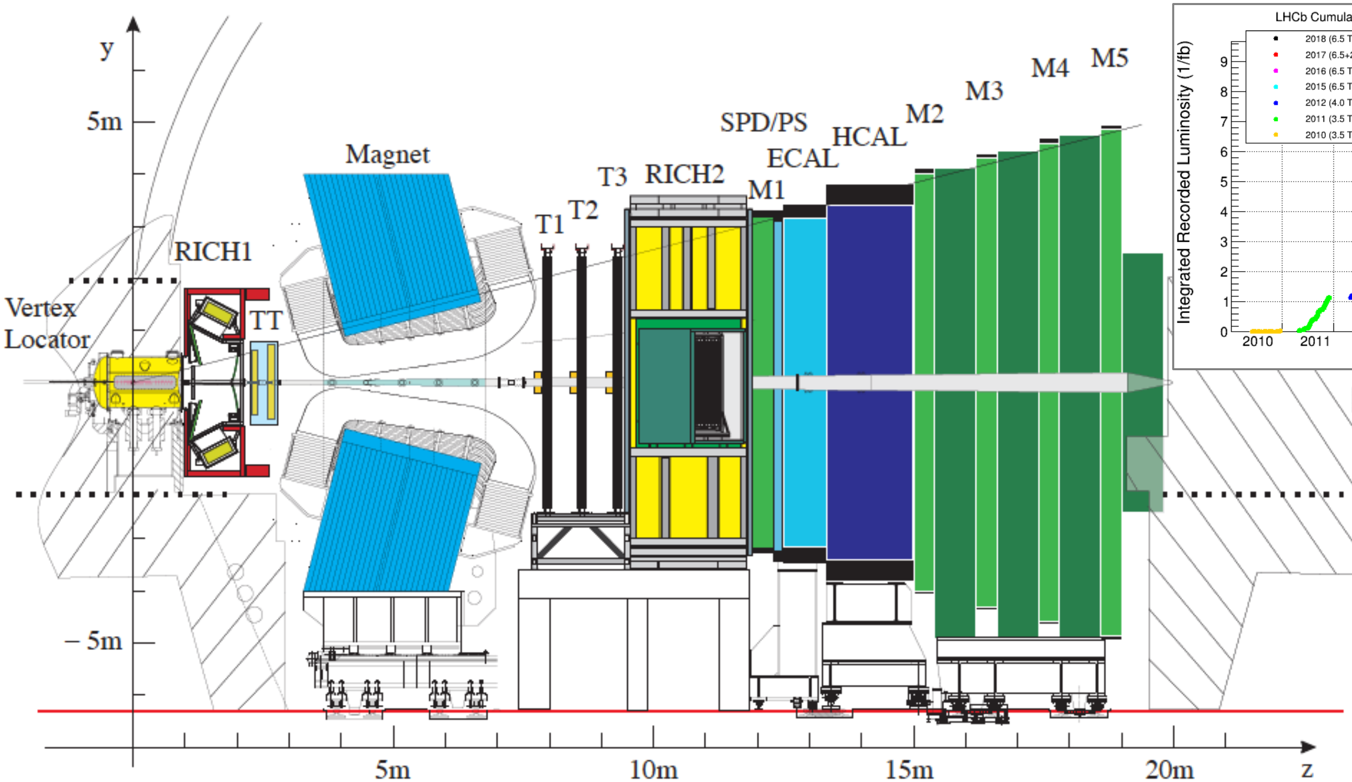
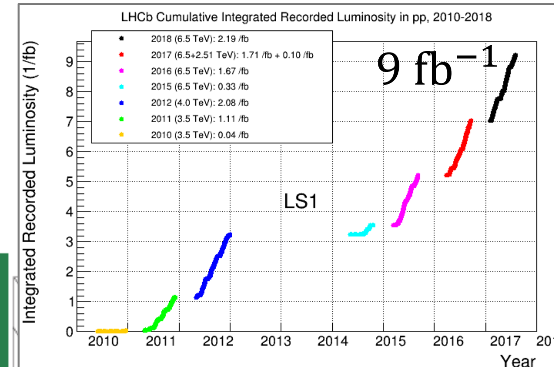
Large Hadron Collider

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 $(\pi \to K) \sim 5\%$

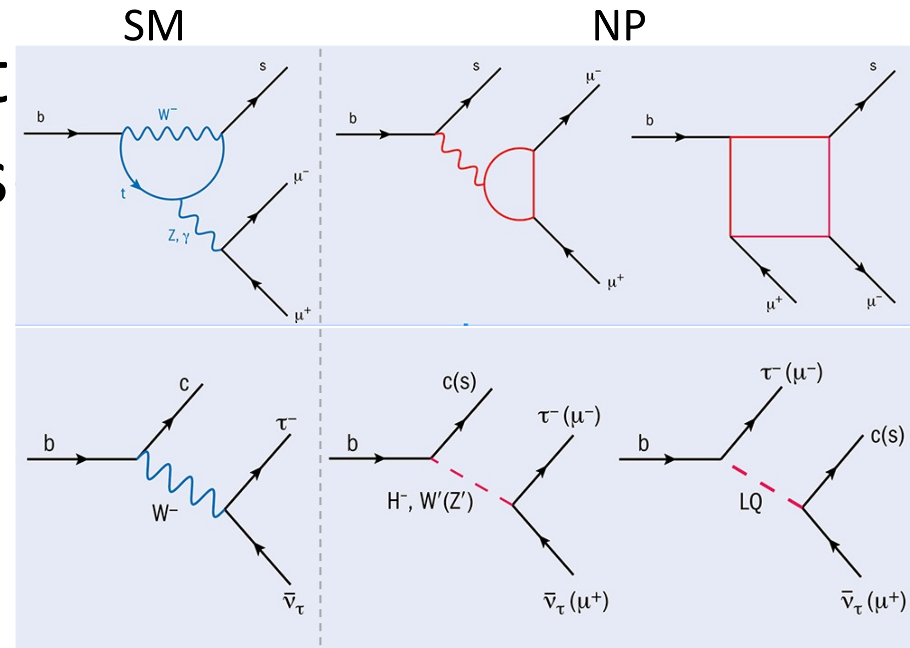
Muon system (M1-M5) $\varepsilon(\mu \to \mu) \sim 97\%$, mis-ID rate $(\pi \to \mu) = 1 - 3\%$

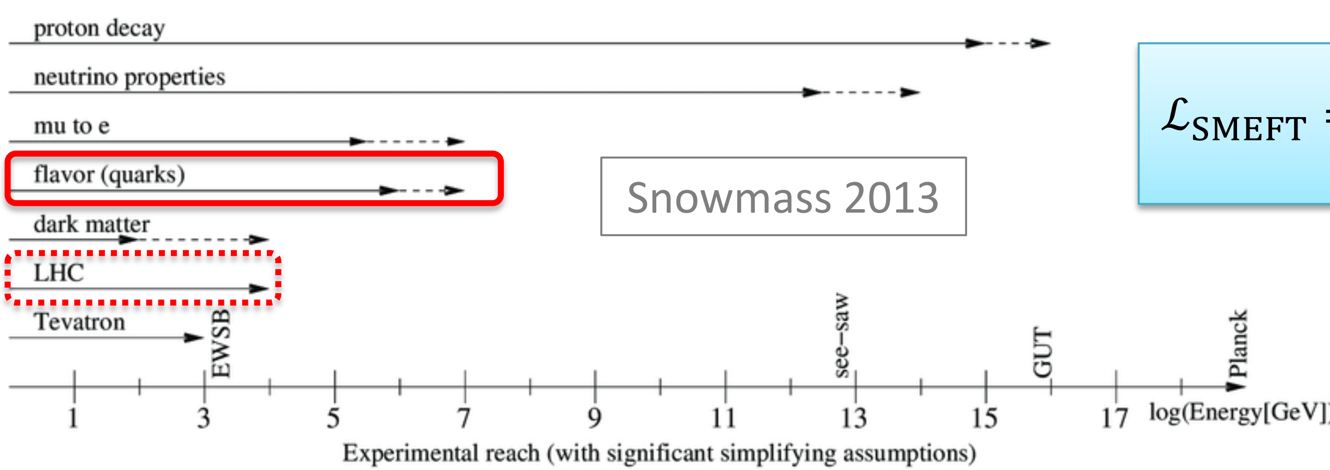
ECAL $\sigma_E/E \sim 10\%/\sqrt{E} \oplus 1\%$ (E in GeV)

HCAL $\sigma_E/E \sim 70\%/\sqrt{E} \oplus 10\%$ (E in GeV)

Indirect search for New Physics

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



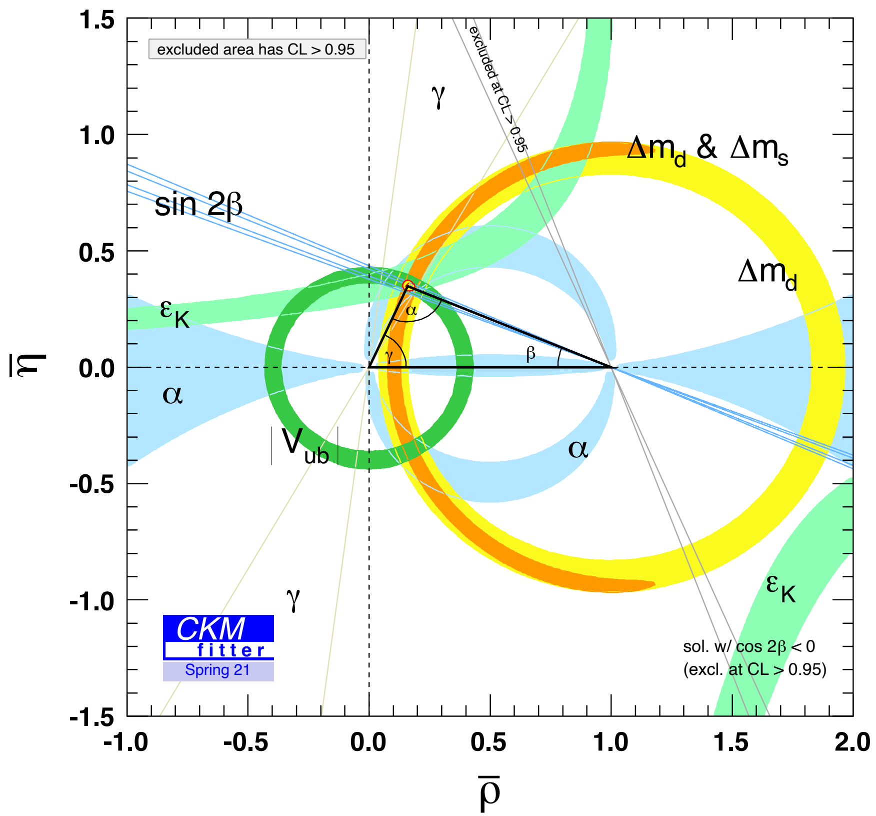


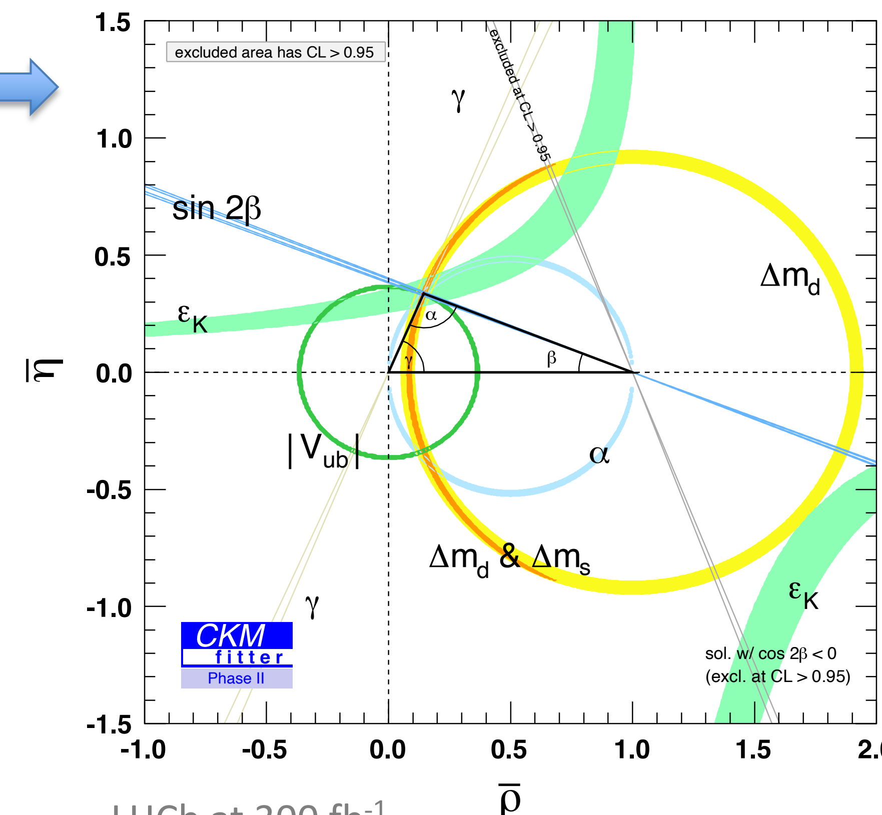
Snowmass 2013

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

Indirect search for NP (cont.)

- Overconstrain the CKM triangle

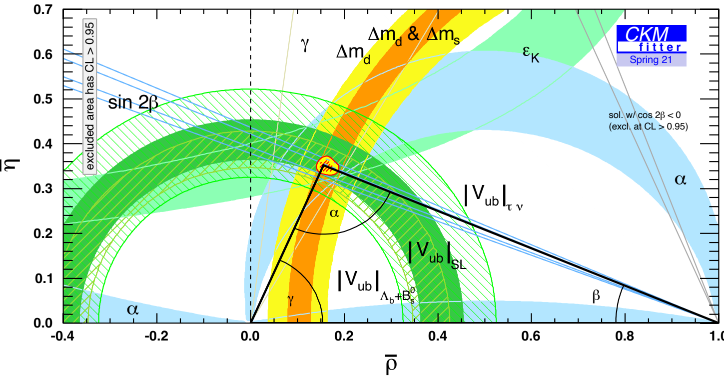


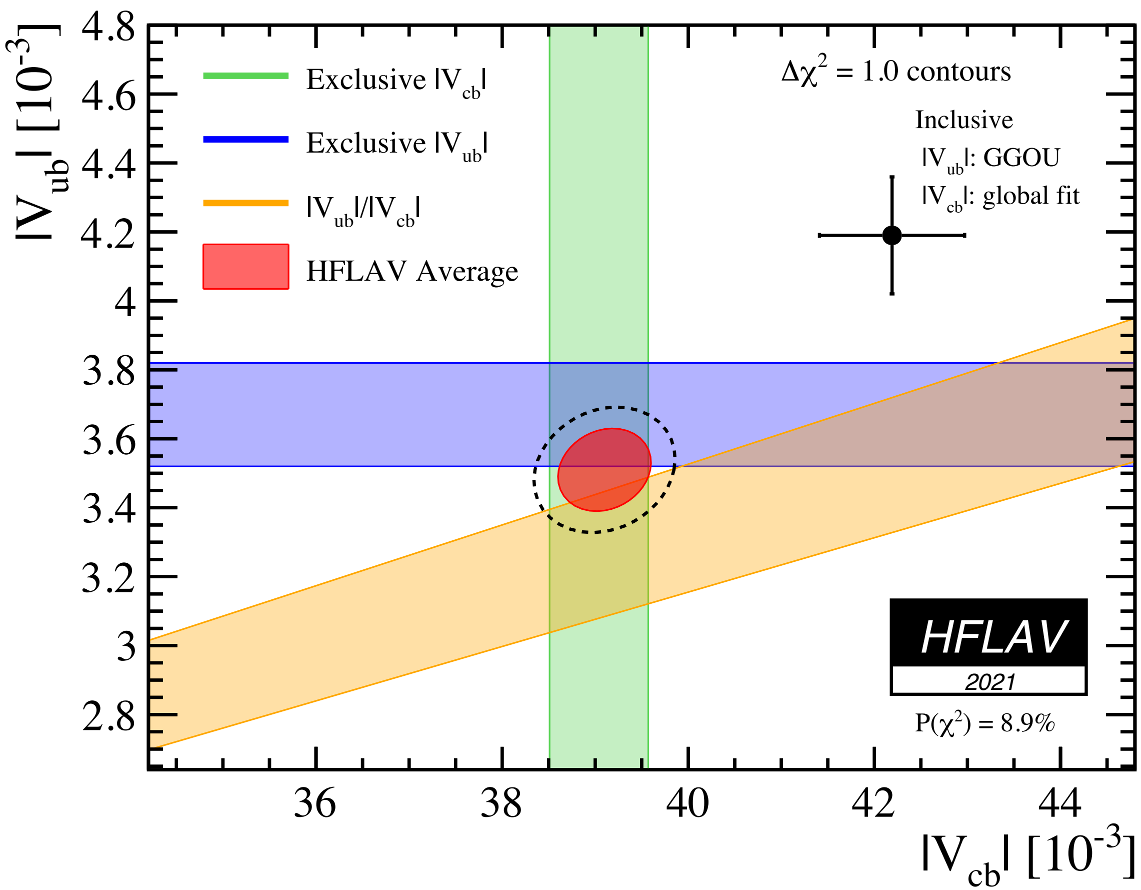


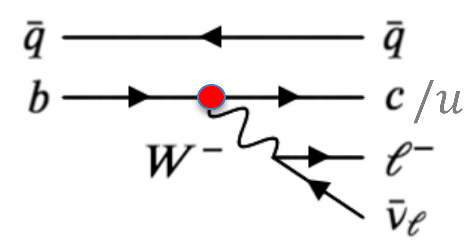
LHCb at 300 fb^{-1},
CMS/ATLAS at 3000 fb^{-1}, Belle II at 50 ab^{-1}.

V_{cb}, V_{ub}

- Some tension between exclusive/inclusive

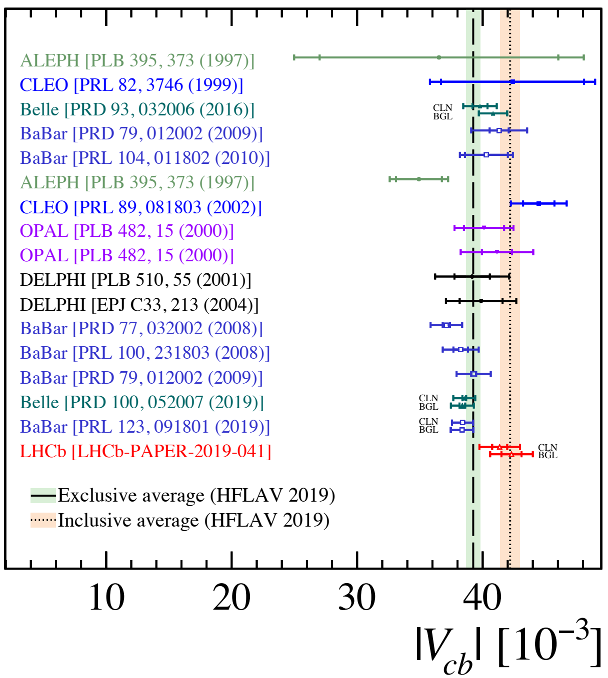




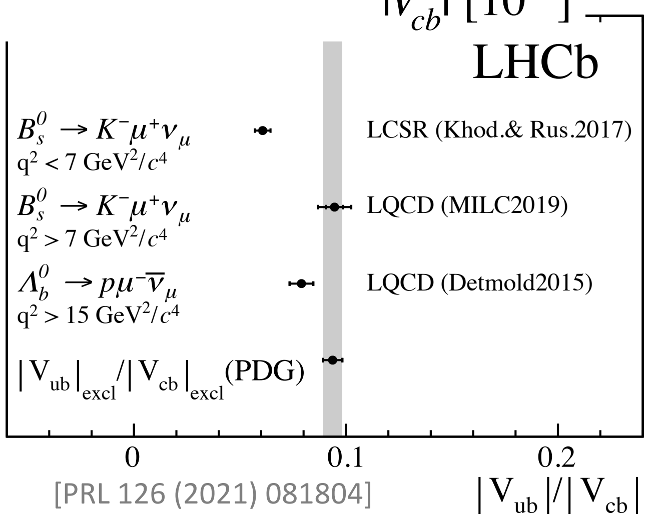


$$d\Gamma \propto |V_{cb}|^2 |f_H|^2$$

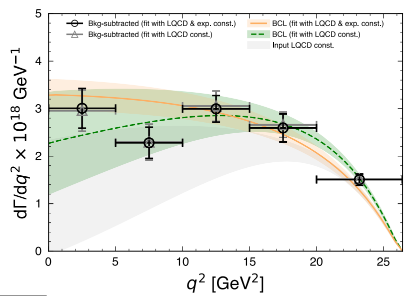
V_{cb}, V_{ub}



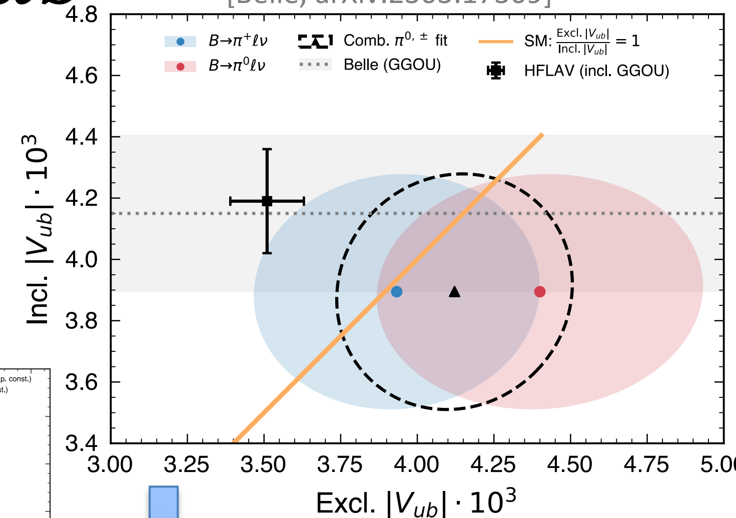
[PRD 101 (2020) 072004]



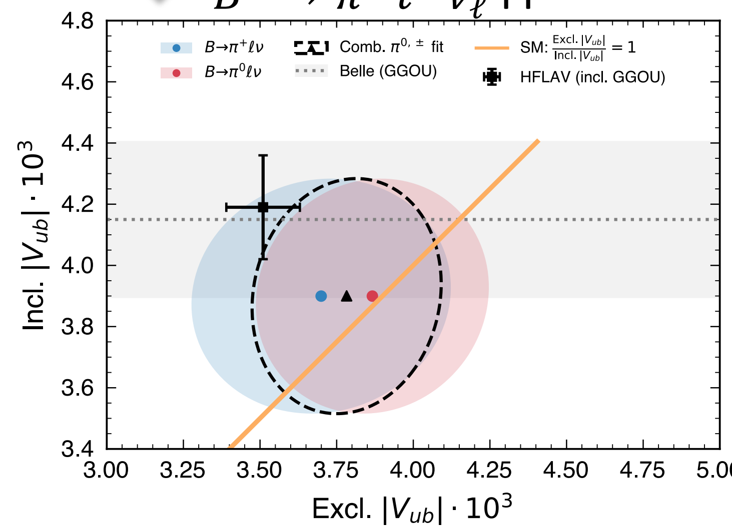
[PRL 126 (2021) 081804]



[Belle, arXiv:2303.17309]

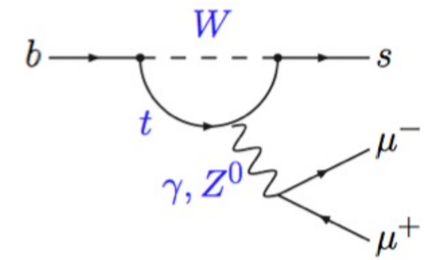


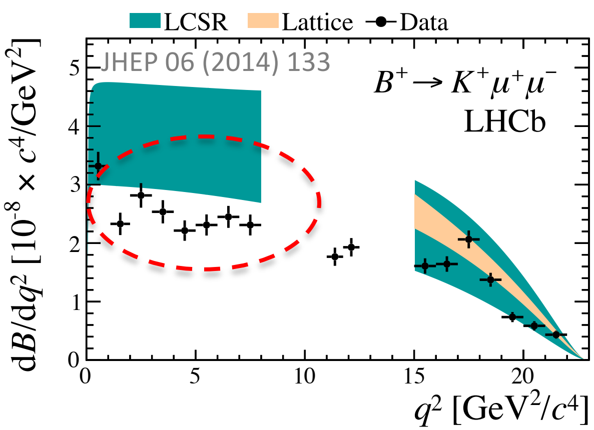
+ w/ exp constraint for $\bar{B}^0 \to \pi^+ \ell^- \bar{\nu}_\ell$ FF

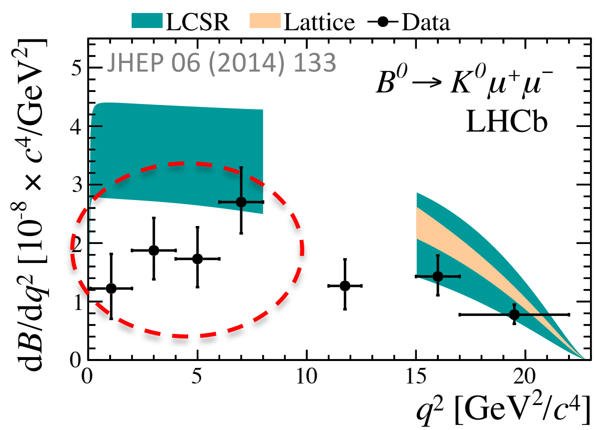


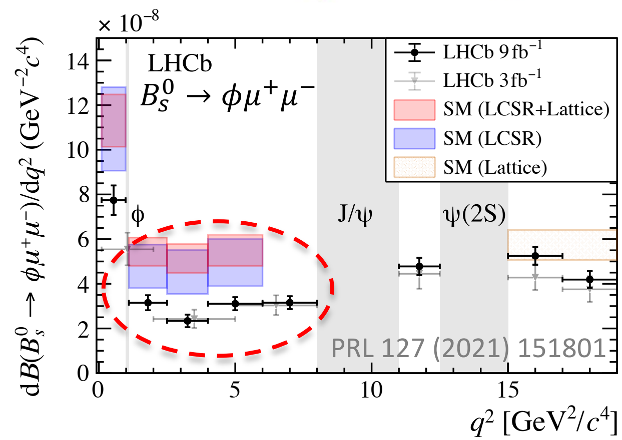
Branching fraction of $b \to s\mu^+\mu^-$

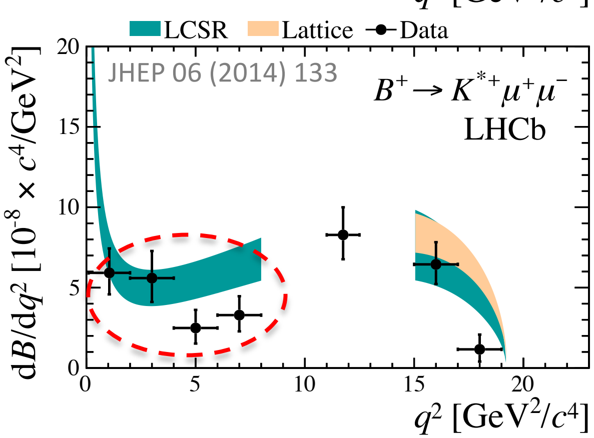
- Pattern of tensions seen, theoretical uncertainty?

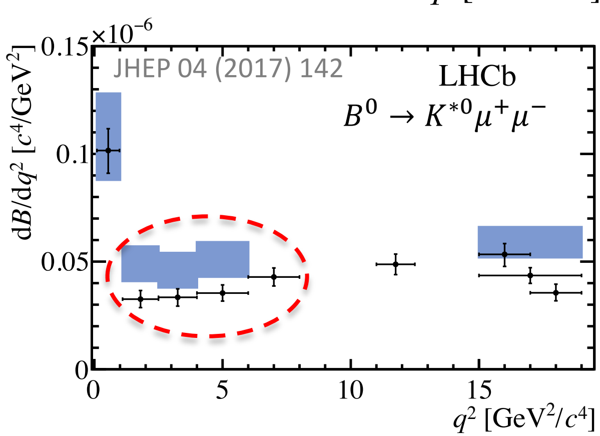


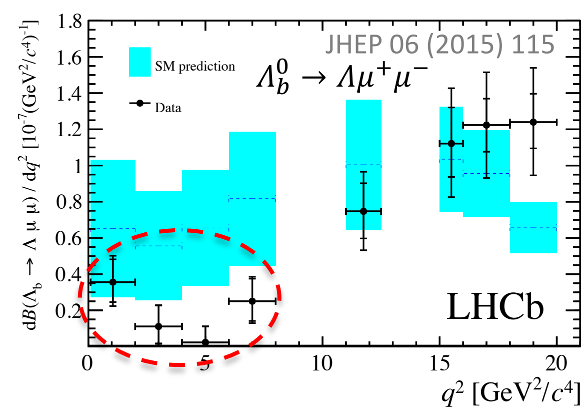








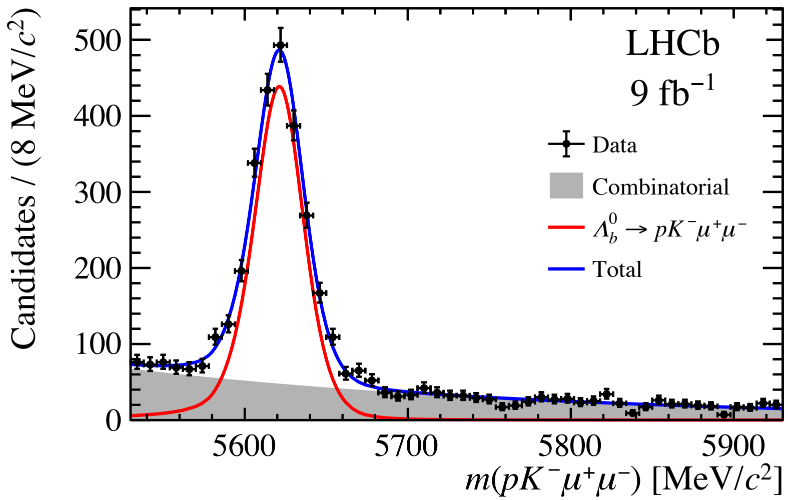


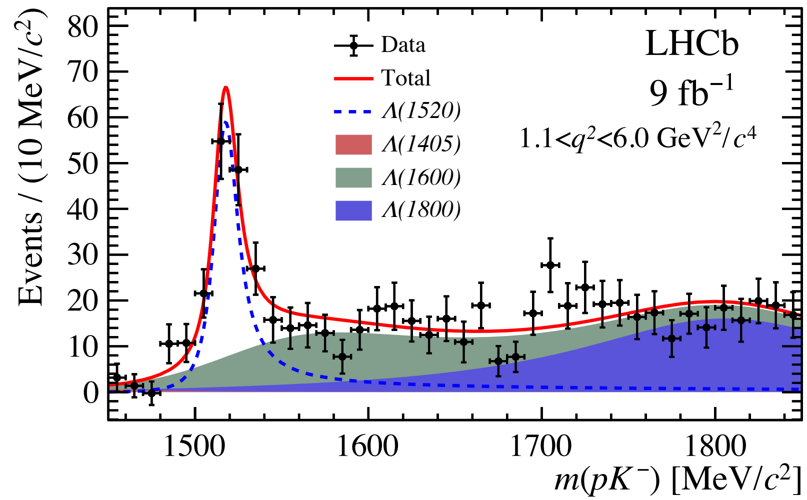


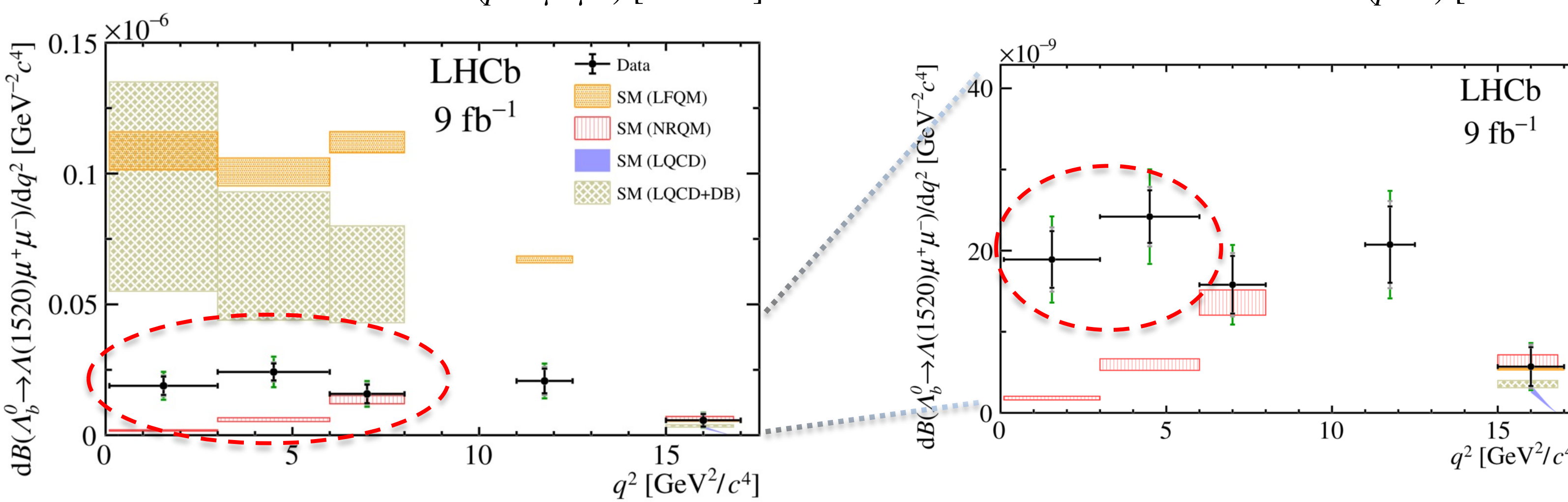
BR of $\Lambda_b^0 \to \Lambda(1520)\mu^+\mu^-$

- First measurement, w/ all data

[arXiv:2302.08262, accepted by PRL]

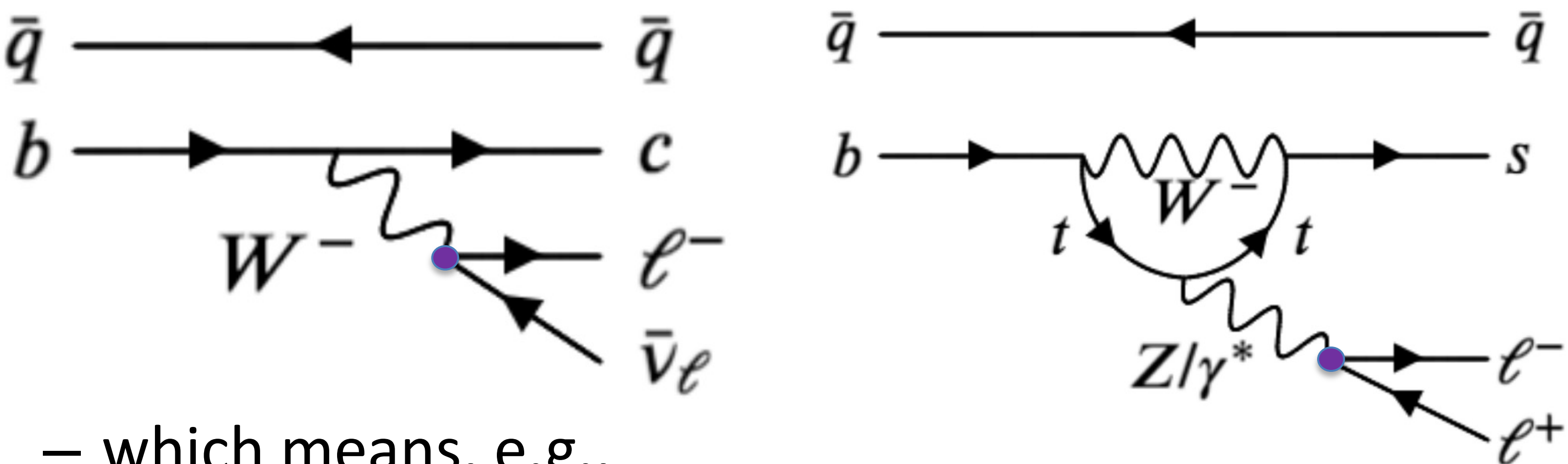






Lepton flavor universality

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



  – which means, e.g.,

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

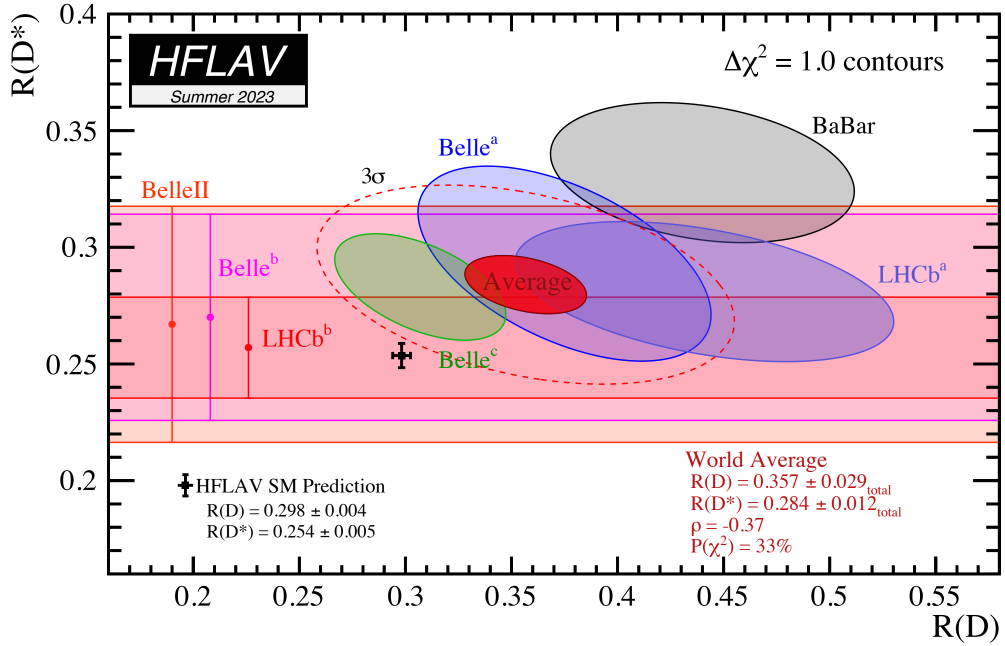
$\mathcal{O}(10^{-4})$ uncertainty
[C. Bobeth *et al.*, JHEP 12 (2007) 040]

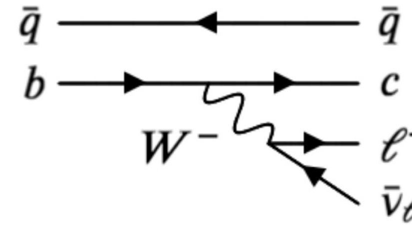
$\mathcal{O}(1\%)$ QED correction
[M. Bordone *et al.*, EJPC 76 (2016) 440]

- Lepton flavor universality violation? New Physics!

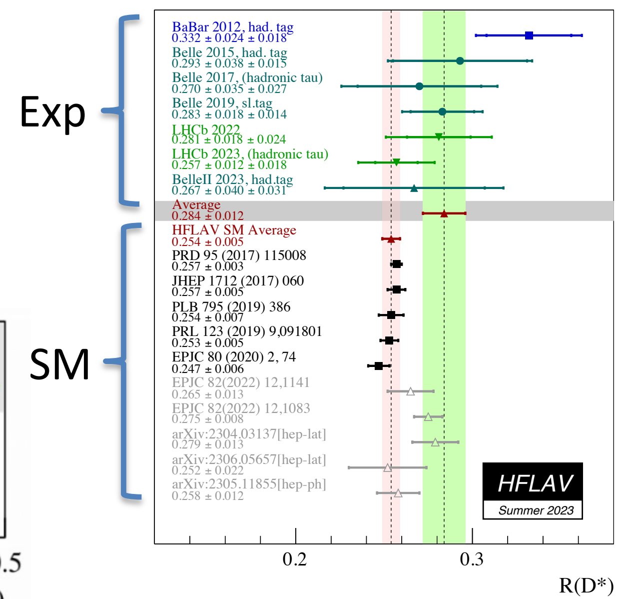
LFU in $b \to c\ell\nu$ decays

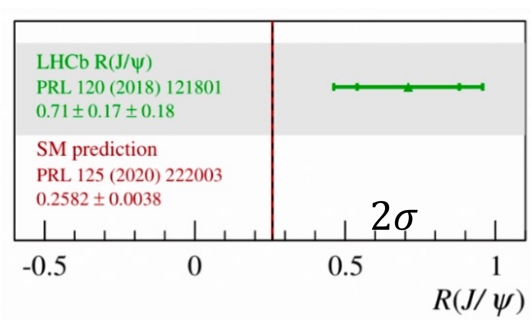
- Deviations from SM seen by Babar/Belle/LHCb

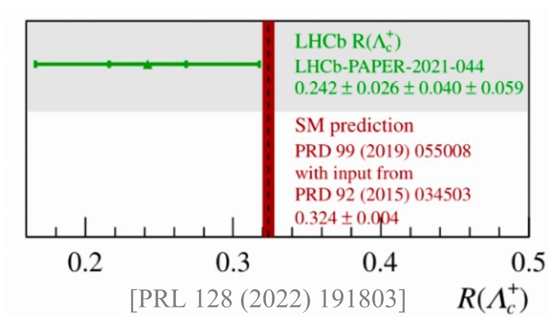




$$R(H_c) = \frac{\mathcal{B}(H_b \to H_c \tau^- \bar{\nu}_\tau)}{\mathcal{B}(H_b \to H_c \mu^- \bar{\nu}_\mu)}$$







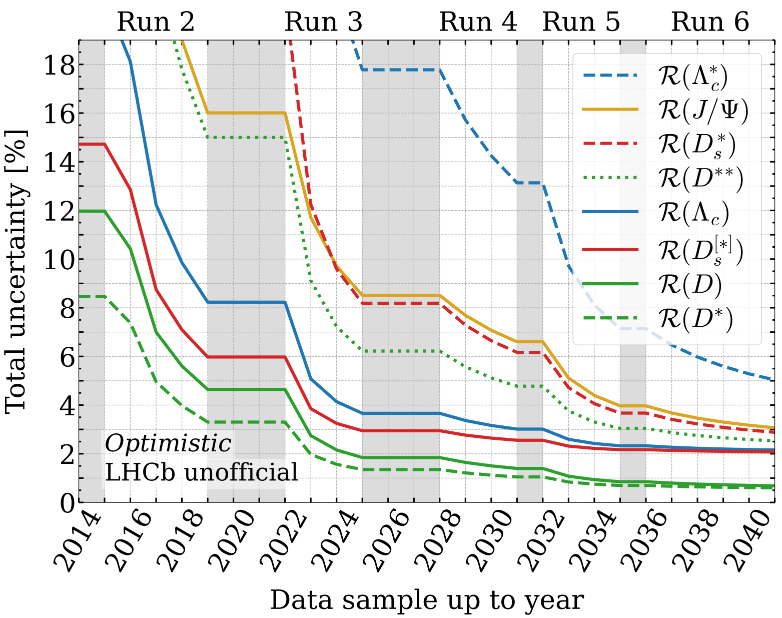
Systematic uncertainty of R(D*)

[LHCb, PRD 108 (2023) 012018]

TABLE V. Summary of relative systematic uncertainties on the ratio $\mathcal{K}(D^{*-})$.

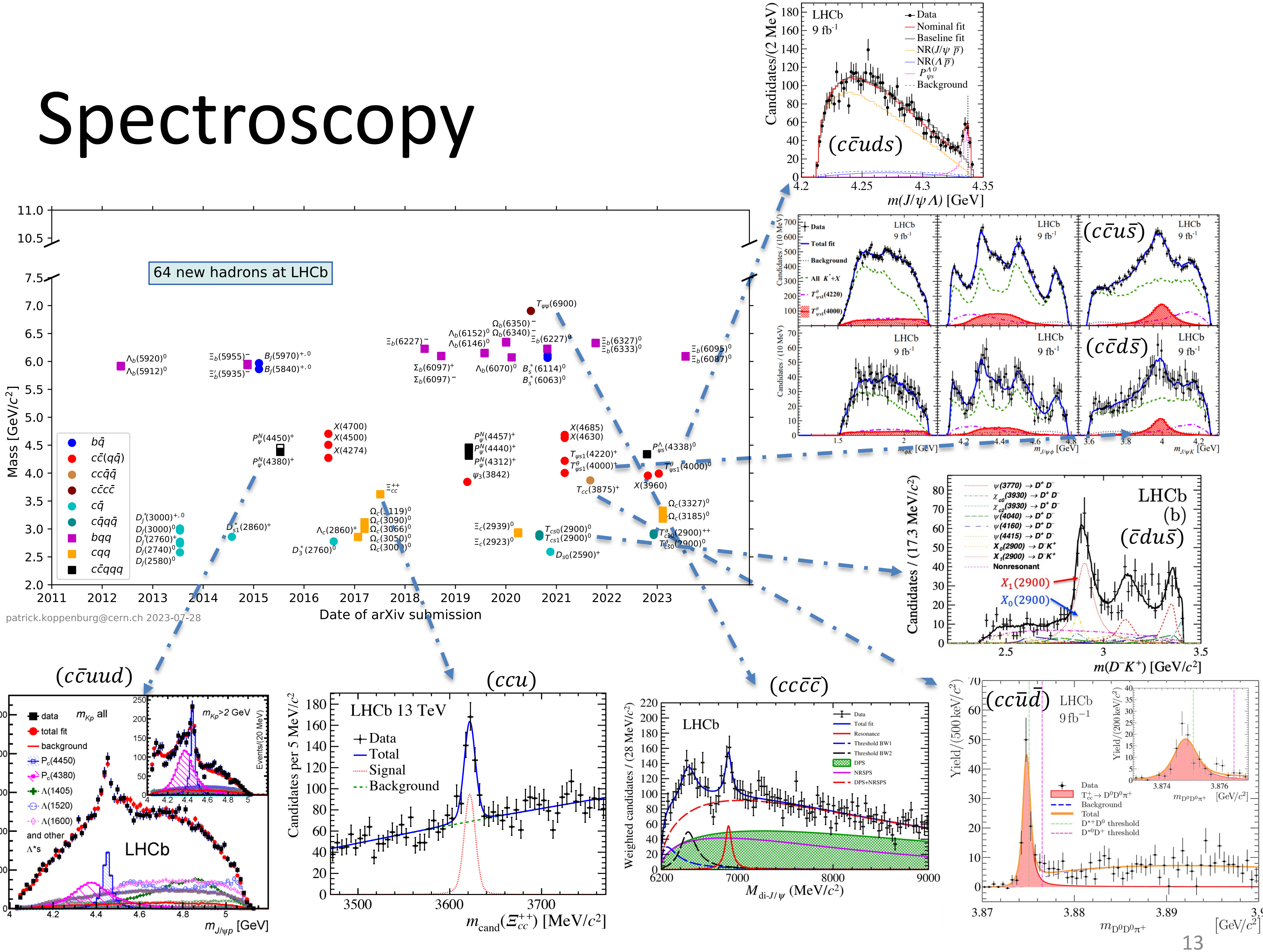
Source	Systematic uncertainty (%)
Signal decay template shape	1.8
Signal decay efficiency	0.9
Fractions of signal τ^+ decays	0.3
Possible contributions from other τ^+ decays	1.0
Fixing the $\bar{D}^{**}\tau^+\nu_\tau$ and $D_s^{**+}\tau^+\nu_\tau$ fractions	$^{+1.8}_{-1.9}$
Normalization mode PDF choice	1.0
Knowledge of the $D_s^+ \to 3\pi X$ decay model	1.0
Specifically the $D_s^+ \to a_1 X$ fraction	1.5
$B \to D^{*-}D_s^+(X)$ template shapes	0.3
$B \to D^{*-}D^0(X)$ template shapes	1.2
$B \to D^{*-}D^+(X)$ template shapes	$^{+2.2}_{-0.8}$
Fixing $B \to D^{*-}D_s^+(X)$ background model parameters	1.1
Fixing $B \to D^{*-}D^0(X)$ background model parameters	1.5

The simulated $B^0 \to D^{*-}\tau^+\nu_\tau$ decays are weighted with form factors using the Caprini-Lellouch-Neubert parametrization [35] and these are used to produce signal templates for the fit. The systematic uncertainty due to the limited knowledge of the form factors is estimated by changing the baseline to the Boyd-Grinstein-Lebed parametrization [36] and this causes a 1.8% relative change in the signal yield and a 0.9% deviation in the signal efficiency. The fraction



[F. U. Bernlochner *et al.*, RMP 94 (2022) 015003]

Spectroscopy



Hunting for the charming beauty tetraquark T_{bc}: LHCb meets theory

Thursday 5 Oct 2023, 13:30 → 18:00 Europe/Zurich

4/S-030 (CERN)

14:00 → 14:30 **Search for isoscalar $bc\bar{u}\bar{d}$ tetraquarks using lattice QCD** 30m

Speaker: Dr Padmanath Madanagopalan (The Institute of mathematical Sciences Chennai)

Padmanath_LHCbT...

14:30 → 15:00 **Prospects for Tbc searches in Run3** 30m

Speaker: Ivan Polyakov (CERN)

Tbc_Search.pdf

15:00 → 15:30 **Tcc and its quark mass dependence from lattice QCD** 30m

Speaker: Sasa Prelovsek

prelovsek_Tbc.pdf

15:30 → 15:50 **Coffee break** 20m

15:50 → 16:20 **Lattice QCD studies of doubly heavy tetraquarks** 30m

Speakers: Randy Lewis, William Parrott (University of Glasgow)

LHCb2023talk.pdf

16:20 → 16:50 **Current status of Tbc and othe tetraquarks with one or more heavy quarks in lattice QCD** 30m

Speaker: Pedro Bicudo

Talk_LHCb2023_Te...

16:50 → 17:20 **Mass predictions from the quark model and the Born-Oppenheimer approximation in QCD** 30m

Speaker: Luciano Maiani (Sapienza Universita e INFN, Roma I (IT))

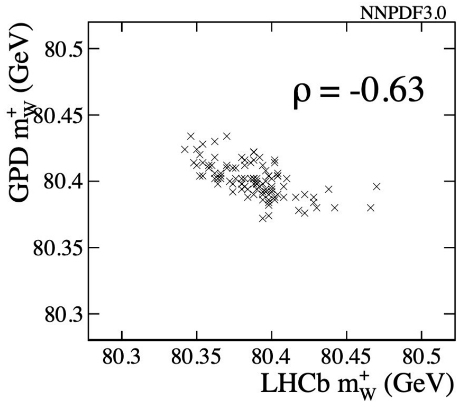
TheDoublyHeavyTe...

https://indico.cern.ch/event/1324964

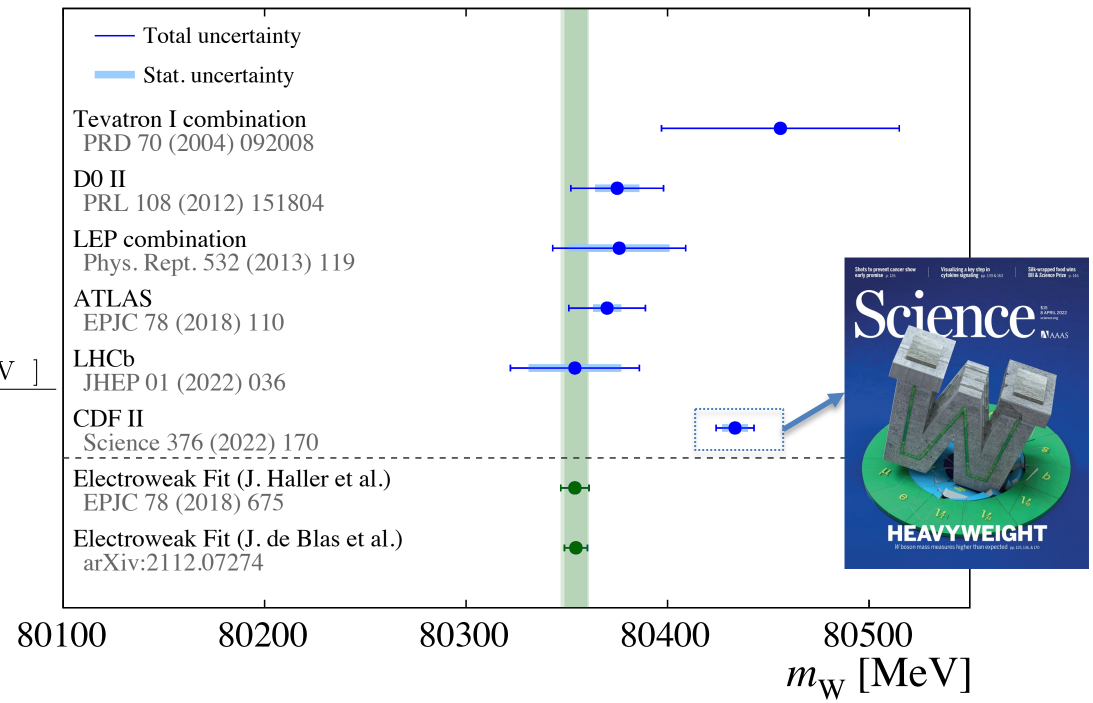
W mass

- CDF results demand more measurements at LHC
- Anti-correlation of PDF at GPD/LHCb

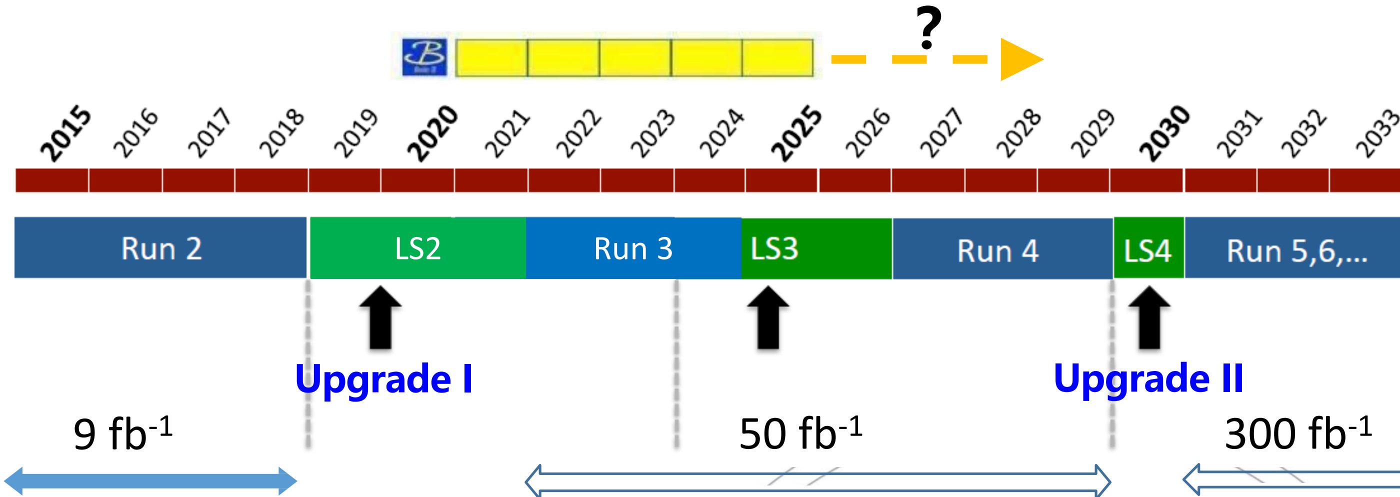
[JHEP 01 (2022) 036]



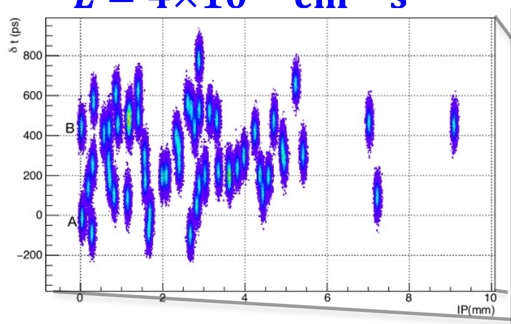
Source	Size [MeV]
Parton distribution functions	9
Theory (excl. PDFs) total	17
Transverse momentum model	11
Angular coefficients	10
QED FSR model	7
Additional electroweak corrections	5
Experimental total	10
Momentum scale and resolution modelling	7
Muon ID, trigger and tracking efficiency	6
Isolation efficiency	4
QCD background	2
Statistical	23
Total	32

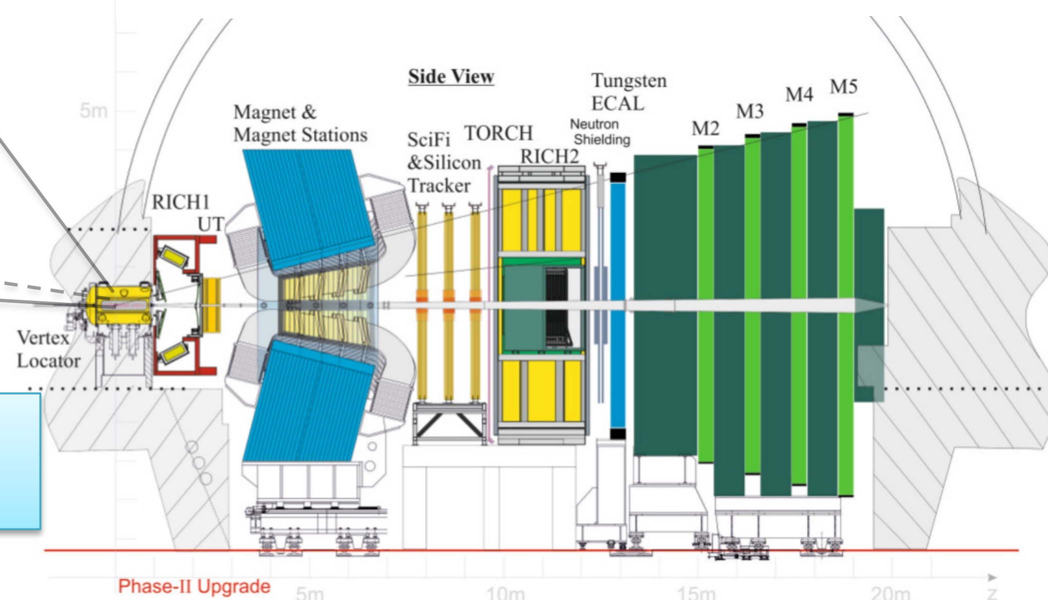


The LHCb upgrades



$L = 4\times10^{32}\ \mathrm{cm^{-2}s^{-1}}$ $L = 2\times10^{33}\ \mathrm{cm^{-2}s^{-1}}$ $L = 2\times10^{34}\ \mathrm{cm^{-2}s^{-1}}$





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

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

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%	–
$B_s^0, B^0 \to \mu^+\mu^-$					
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	90% [264]	34%	–	10%	21% [609]
$\tau_{B_s^0 \to \mu^+\mu^-}$	22% [264]	8%	–	2%	–
$S_{\mu\mu}$	–	–	–	0.2	–
$b \to c\ell^-\bar{\nu}_l$ **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

- LQCD inputs eagerly needed by LHCb, e.g.,
  - V_{cb}, V_{ub}
  - $b \to s\mu^+\mu^-$ BR
  - $\mathcal{R}_{D^*}$
  - Spectroscopy
  - W mass
- Such inputs become more important with LHCb upgrade (50 fb^{-1}) & upgrade-II (300 fb^{-1})