Rare decays of B hadrons

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on behalf of the LHCb collaboration with results from Belle

LP2019

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LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

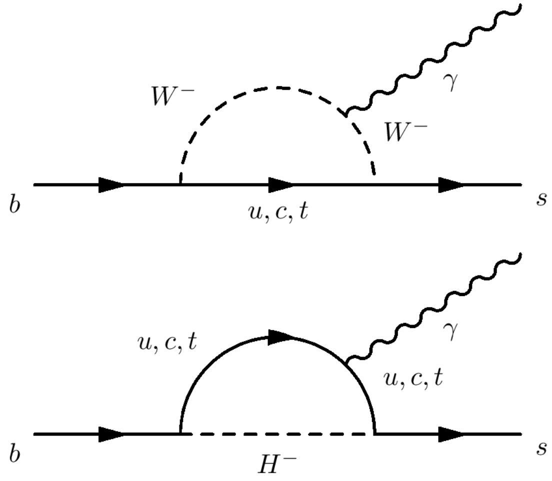
LHCb

BELLE

cnrs

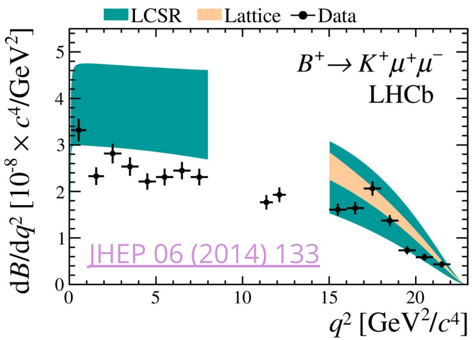
Why rare B decays?

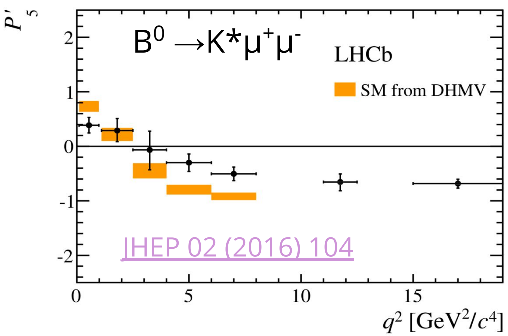
- FCNC sensitive to indirect effects of New Physics (NP) in loops
  - branching fractions, angular distributions, etc.
- Access to much larger scales than direct searches

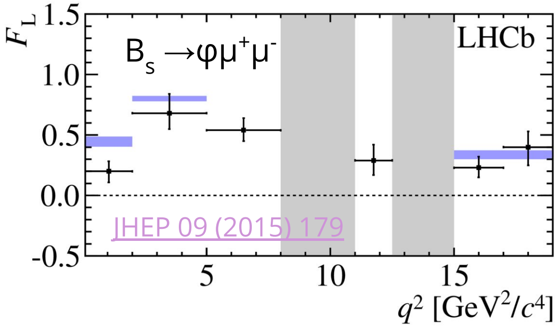


Intriguing deviations in rare B decays

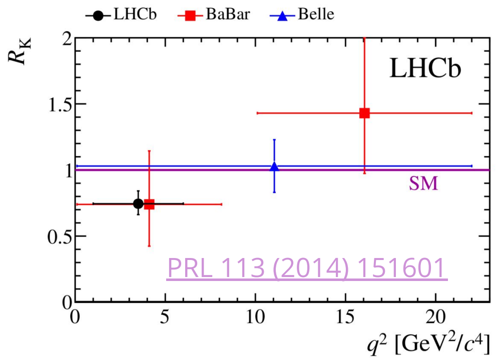
Differential BR and angular distributions

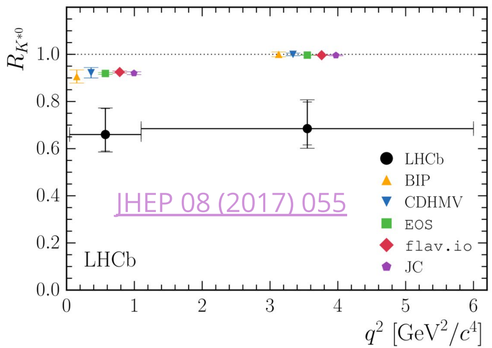






Lepton Flavour Universality (LFU) tests





Effective Hamiltonian

Model independent description in effective field theory [Buchalla et al.]:

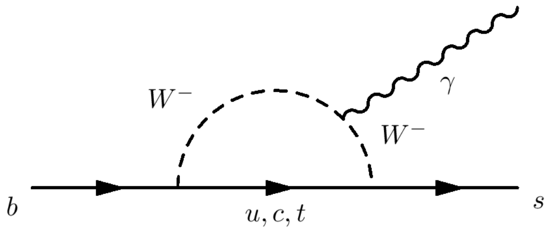
$$H_{eff} \propto V_{tb} V_{ts}^{*} \sum_i \left(C_i \mathcal{O}_i + C_i' \mathcal{O}_i' \right)$$

Complete basis of 4-body operators contributing to different final states:

$$O_7^{(\prime)} \propto (\bar{s} \sigma_{\mu\nu} P_{R(L)} b) F^{\mu\nu}$$
$$O_9^{(\prime)} \propto (\bar{s} \gamma_\mu P_{L(R)} b)(\bar{l} \gamma_\mu l)$$
$$O_{10}^{(\prime)} \propto (\bar{s} \gamma_\mu P_{L(R)} b)(\bar{l} \gamma_\mu \gamma_5 l)$$
$$O_S^{(\prime)} \propto (\bar{s} P_{L(R)} b)(\bar{l} l)$$
$$O_P^{(\prime)} \propto (\bar{s} P_{L(R)} b)(\bar{l} \gamma_5 l)$$

Transition	$C_7^{(\prime)}$	$C_9^{(\prime)}$	$C_{10}^{(\prime)}$	$C_{S,P}^{(\prime)}$
$b \to s\gamma$	X			
$b \to \ell^+\ell^-$			X	X
$b \to s\ell^+\ell^-$	X	X	X	

Radiative decays



Sensitive to right-handed currents through photon polarisation

$$\alpha_\gamma = \frac{P(\gamma_L) - P(\gamma_R)}{P(\gamma_L) + P(\gamma_R)}$$

at leading order (LO) in the SM:

$$\alpha_\gamma^{LO} = \frac{|C_7|^2 - |C_7'|^2}{|C_7|^2 + |C_7'|^2}$$

Photon polarization in $B_s \to \phi\gamma$

arXiv:1905.06284

Time dependent decay rate for f_{CP} states gives access to photon polarization:

$$\Gamma(t) \propto e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_{(s)}}{2}\right) - \mathcal{A}^{\Delta}\sinh\left(\frac{\Delta\Gamma_{(s)}}{2}\right) \pm \mathcal{C}_{CP}\cos\left(\Delta m_{(s)}t\right) \mp \mathcal{S}_{CP}\sin\left(\Delta m_{(s)}t\right)\right]$$

$$\mathcal{A}^{\Delta}_{\phi\gamma} = -0.98^{+0.46}_{-0.52}{}^{+0.23}_{-0.20}$$

PRL 118(2017)2,021801

$$\mathcal{A}^{\Delta}_{\phi\gamma} \simeq \frac{\mathrm{Re}(e^{-i\phi_s}C_7\,C_7')}{|C_7|^2+|C_7'|^2} \qquad S_{\phi\gamma} \simeq \frac{\mathrm{Im}(e^{-i\phi_s}C_7\,C_7')}{|C_7|^2+|C_7'|^2}$$

Require knowledge of the B_s flavour at production

⇩

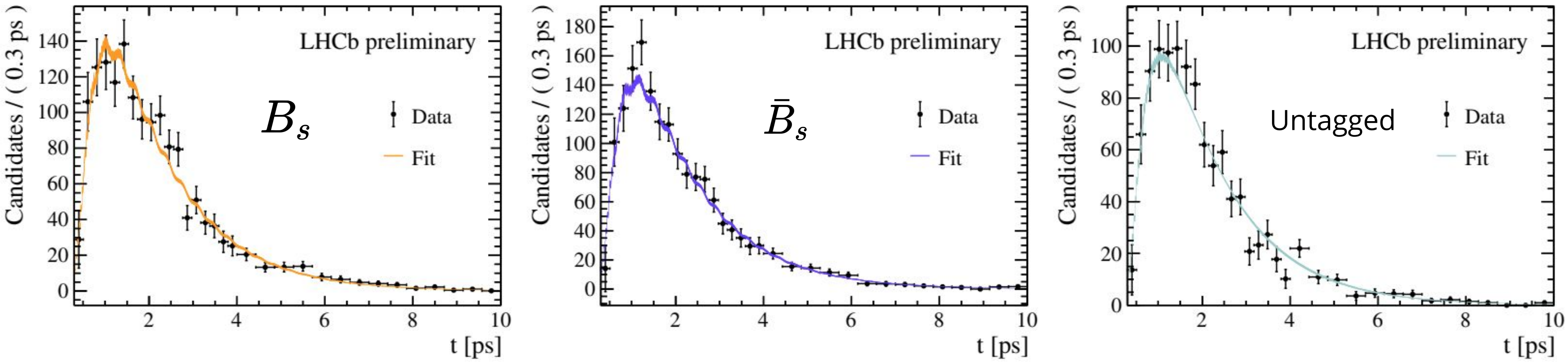
NEW this year

3 fb^{-1} LHCb data

Photon polarization in $B_s \to \phi\gamma$

arXiv:1905.06284

- Fit time-dependent decay rate in $B_s \to \phi\gamma$ using B tagging information:



$$S_{\phi\gamma} = 0.43 \pm 0.30 \pm 0.11$$
$$C_{\phi\gamma} = 0.11 \pm 0.29 \pm 0.11$$
$$\mathcal{A}^{\Delta}_{\phi\gamma} = -0.67\,^{+0.37}_{-0.41} \pm 0.17$$

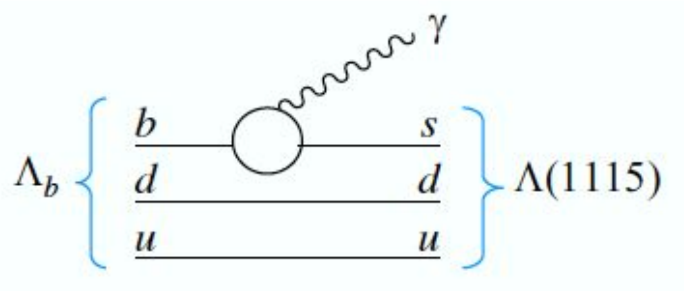
First measurement in B_s system

Compatible with SM and previous result for A^{Δ}

First observation of $\Lambda_b \to \Lambda^0\gamma$

PRL 123 031801 (2019)

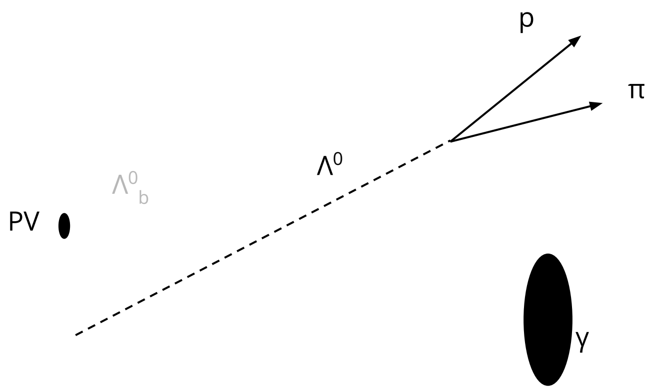
Baryonic b → sγ not yet observed
BR < $1.9\cdot10^{-3}$ [CDF PhysRevD.66.112002]



$BR_{SM} \in [0.06, 1]\times10^{-5}$ [Wang et al., Mannel et al., Gan et al., Faustov et al.]

Gives access to photon polarisation
[Mannel & Recksiegel, Hiller & Kagan]

Very challenging reconstruction → dedicated reconstruction in Run 2



Huge combinatorial background mitigated with performant MVA

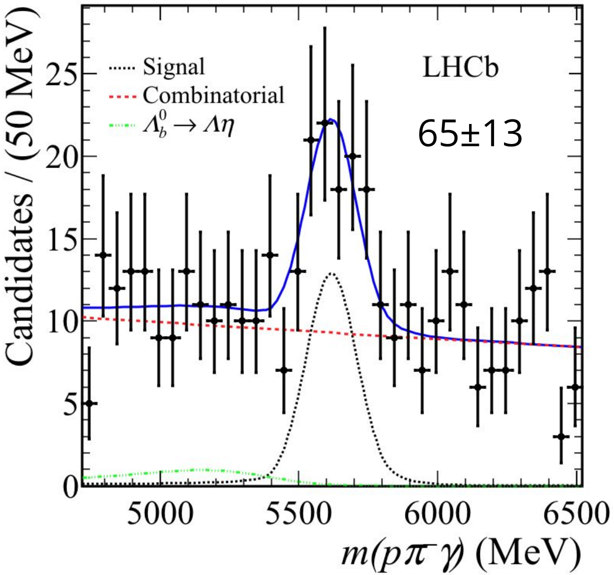
First observation of $\Lambda_b \to \Lambda^0\gamma$

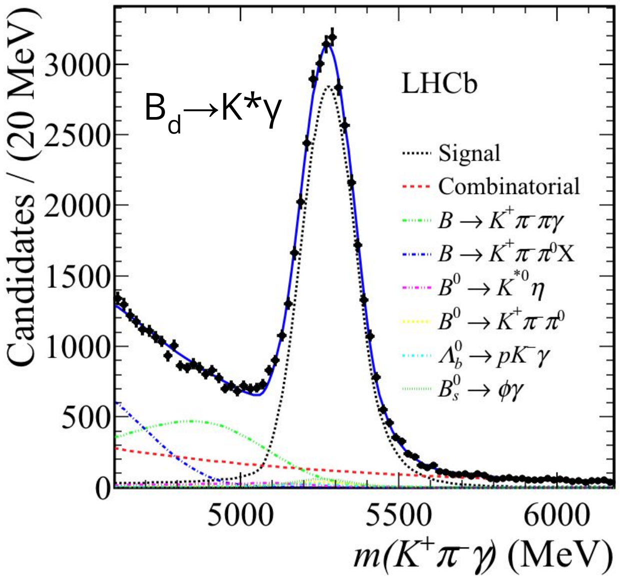
PRL 123 031801 (2019)

LHCb 2016 data ($1.7\ fb^{-1}$)

Significance of 5.6σ
First observation!

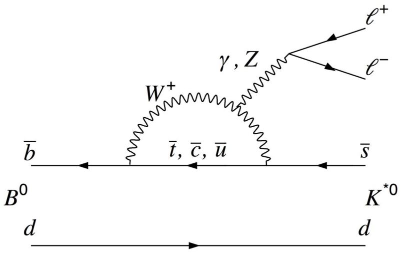
Opens doors to photon polarisation measurement

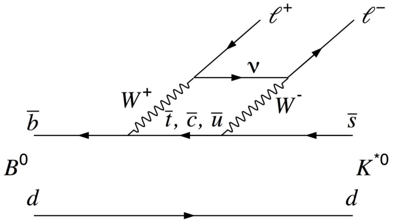


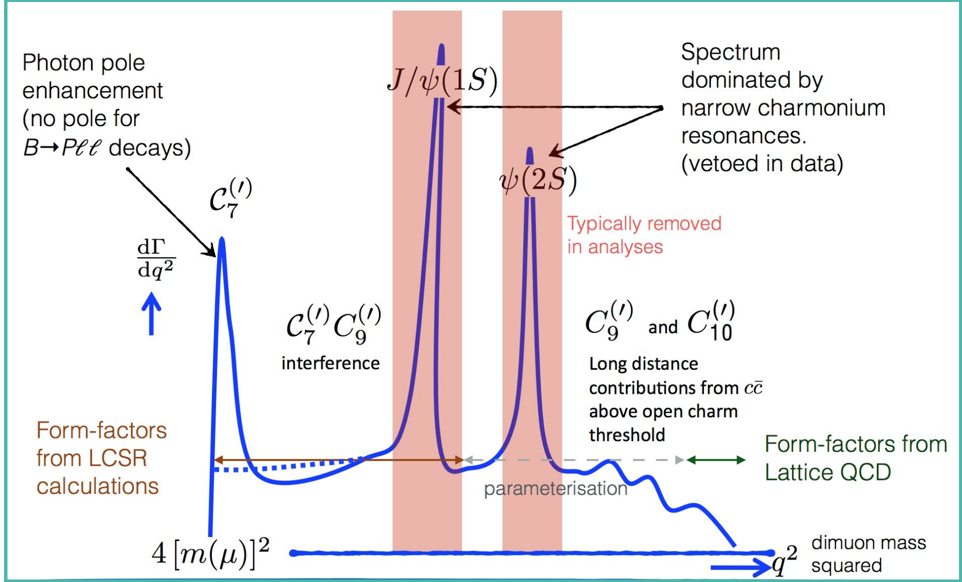


$$\mathcal{B}(\Lambda_b^0 \to \Lambda\gamma) = (7.1 \pm 1.5 \pm 0.6 \pm 0.7) \times 10^{-6}$$

Semileptonic penguin decays



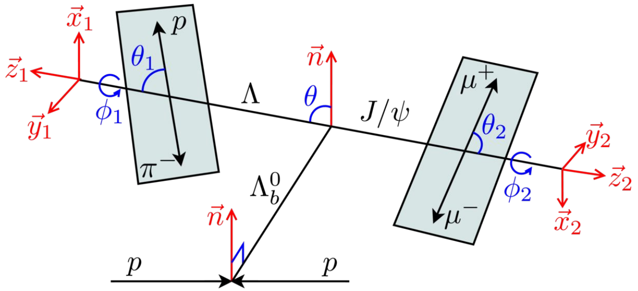




Full angular analysis of $\Lambda^0_b \to \Lambda\mu^+\mu^-$

JHEP 09 (2018) 146

Richer angular distribution than meson decays

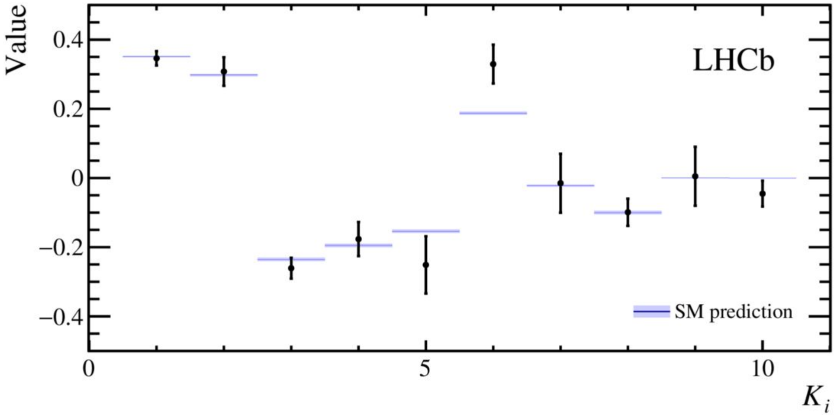


Method of moments [JHEP 11 (2017) 138]

→ full set of angular observables

$$\frac{d^5\Gamma}{d\Omega} = \frac{3}{32\pi^2} \sum_i^{34} K_i f_i(\Omega)$$

LHCb 2011-2016 data (5 fb^{-1})

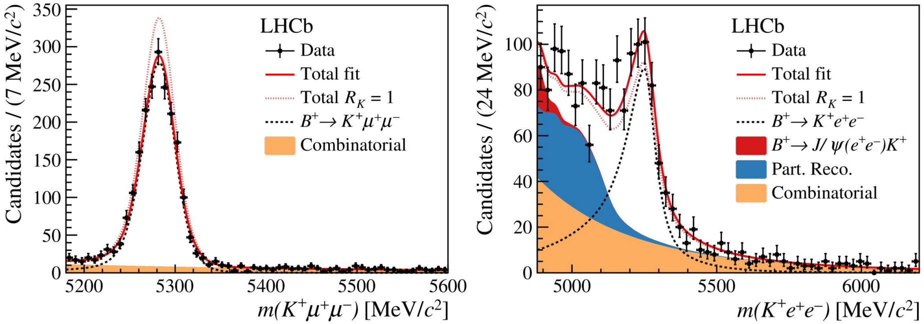


b → sll with electrons

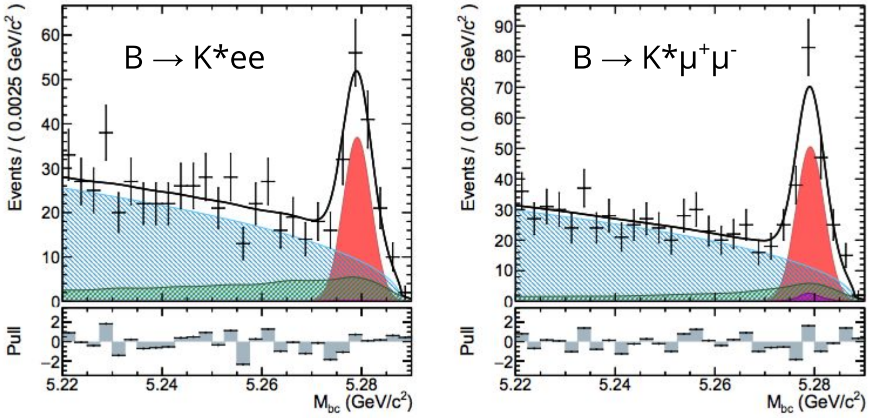
Theoretically, same behaviour as for muons → LFU tests

A challenge at LHCb:

Much more similar to muons at Belle:



PRL 122 (2019) 191801



arXiv:1904.02440

$b \longrightarrow sll$ with electrons at LHCb

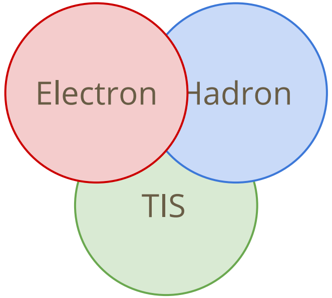
Hardware trigger

Larger ECAL occupancy → tighter thresholds for electrons:

- e p_T > 2700/2400 MeV in 2012/2016
- μ p_T > 1700/1800 MeV in 2012/2016

[LHCb-PUB-2014-046, 2019 JINST 14 P04013]

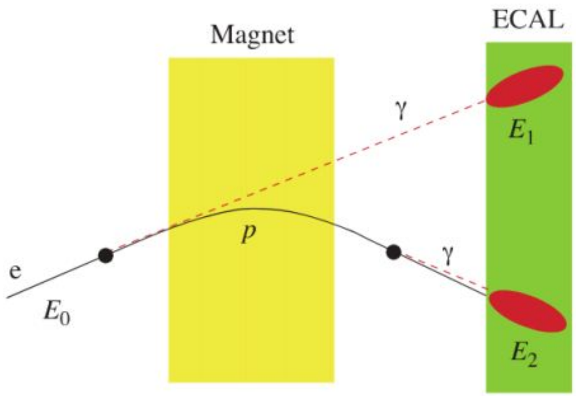
Mitigate including hadron trigger and events triggered independently of the signal (TIS)



Interaction with detector material

Electrons radiate much more Bremsstrahlung

Recovery procedure in place



- miss some photons and add fake ones
- ECAL resolution worse than tracking

→ worse mass resolution for electron modes

How do we measure LFU?

In the SM:

$$R_H = \frac{BR(B \to H\mu^+\mu^-)}{BR(B \to He^+e^-)} = 1$$

Experimentally:

$$R_H = \boxed{\frac{N(B \to H\mu^+\mu^-)}{N(B \to He^+e^-)}} \times \boxed{\frac{\epsilon(B \to He^+e^-)}{\epsilon(B \to H\mu^+\mu^-)}}$$

from mass fit

from MC and calibration samples

Exploit the well tested LFU in J/ψ modes

$$r_{J/\psi} = \frac{BR(B \to HJ/\psi(\mu^+\mu^-))}{BR(B \to HJ/\psi(e^+e^-))} = 1$$

- as stringent cross-check
- to build double ratio at LHCb → cancel systematic effects

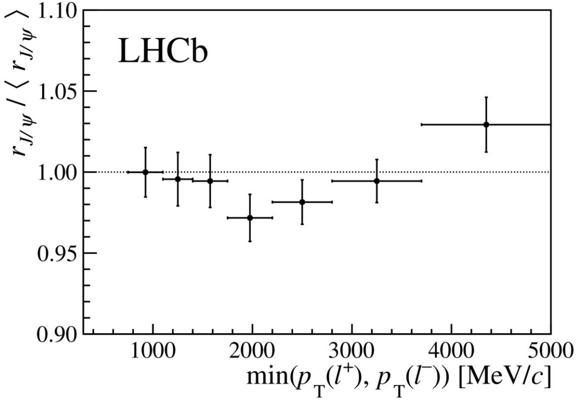
$$R_H = \frac{\frac{N(B \to H\mu^+\mu^-)}{N(B \to HJ/\psi(\mu^+\mu^-))}}{\frac{N(B \to He^+e^-)}{N(B \to HJ/\psi(e^+e^-))}} \times \frac{\frac{\epsilon(B \to He^+e^-)}{\epsilon(B \to HJ/\psi(e^+e^-))}}{\frac{\epsilon(B \to H\mu^+\mu^-)}{\epsilon(B \to HJ/\psi(\mu^+\mu^-))}}$$

Updated R_K from LHCb

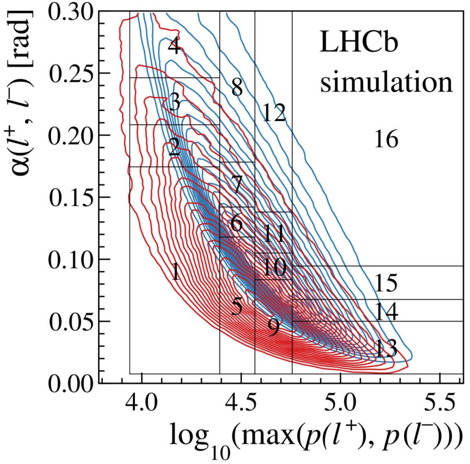
PRL 122 (2019) 191801

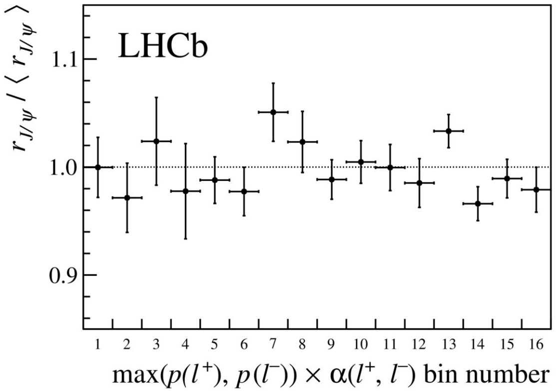
Re-optimised analysis of 2011-2016 data (5 fb^{-1}) in $1.1 < q^2 < 6.0$ GeV^2

- $r_{J/\psi}$ cross-check: $$r_{J/\psi} = 1.014 \pm 0.035$$



If deviations assumed to be genuine → 0.1% on R_K

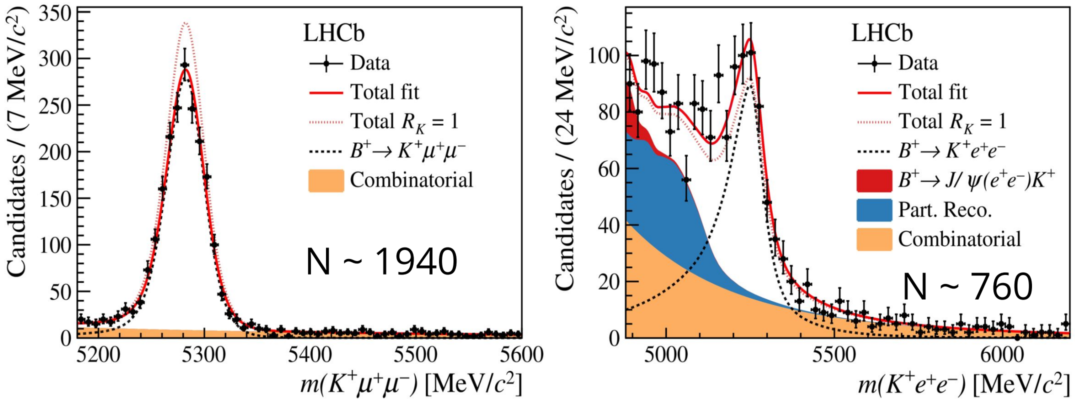




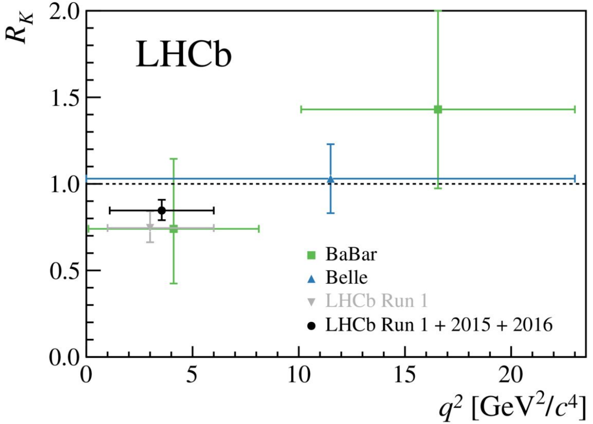
Updated R_K from LHCb

PRL 122 (2019) 191801

Factor 2 larger yields than in previous analysis
still statistically dominated by electron mode



$$R_K = 0.846^{+0.060+0.016}_{-0.054-0.014}$$



compatible with previous analysis and ~2.5σ from SM

Still x2 B decays recorded by LHCb to be analysed!

Updated R_{K*} from Belle

arXiv:1904.02440

New measurement from Belle using full data-set

- charged R_{K*+} measured for the first time
- K* reconstructed from $K^+\pi^-$, $K_S\pi^+$ and $K^+\pi^0$

R_{K*} measured as single ratio but stringent cross-checks performed:

- measurement of BR($B \rightarrow K^* J/\psi$): compatible with world average
- $r_{J/\psi}$ test:

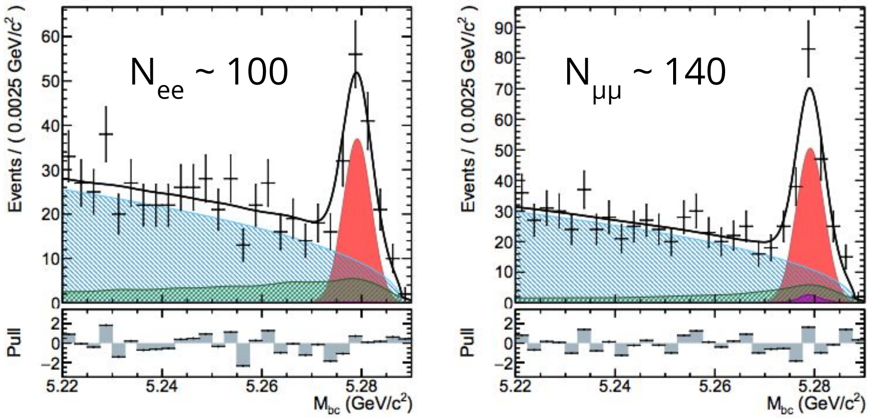
$$r_{J/\psi} = 1.015 \pm 0.025 \pm 0.038$$

Validates efficiency determination

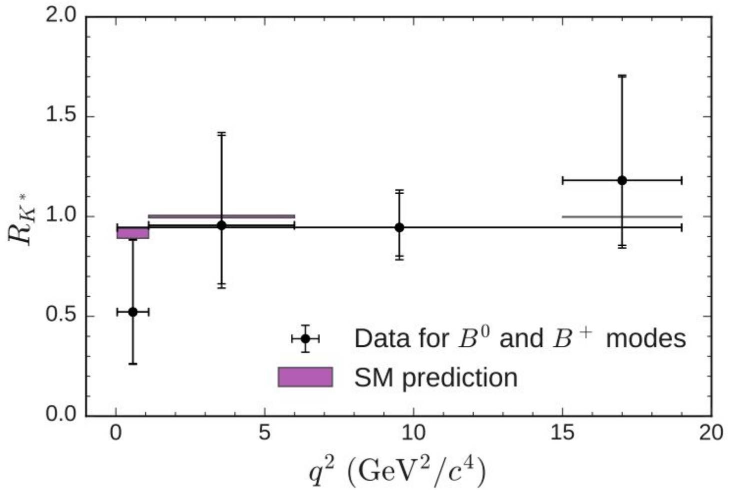
Updated R_{K^*} from Belle

arXiv:1904.02440

Main backgrounds: combinatorial, misidentification, charmonium and peaking



Measure charged and neutral modes separately and weighted average in various q^2 bins:



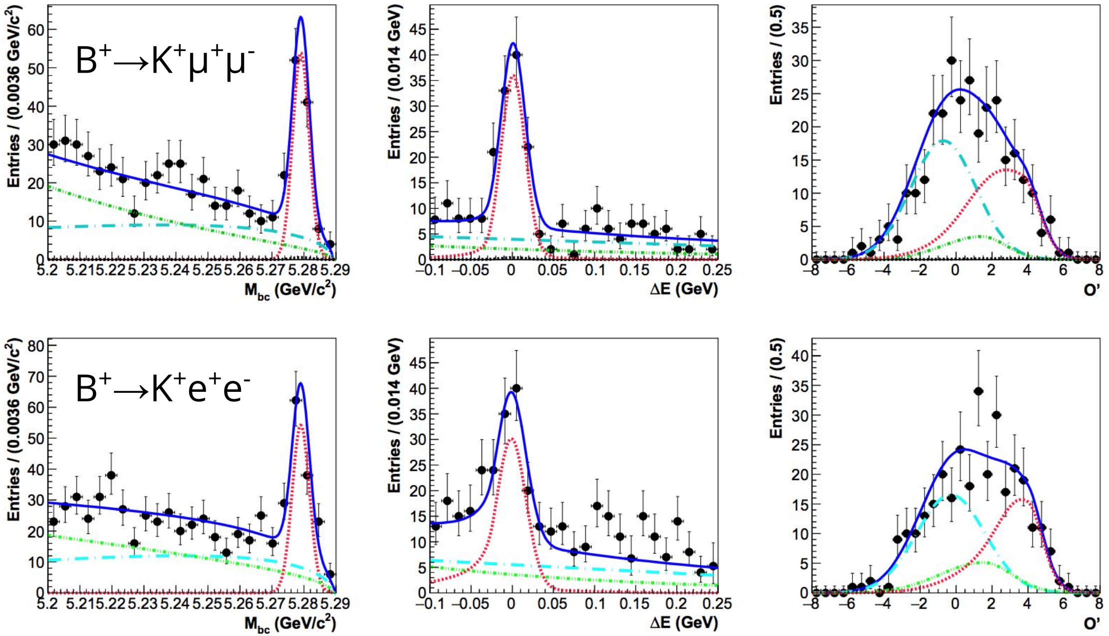
Results compatible with SM and LHCb measurement

Updated R_K from Belle

arXiv:1908.01848

Updated measurement with full Belle data sample

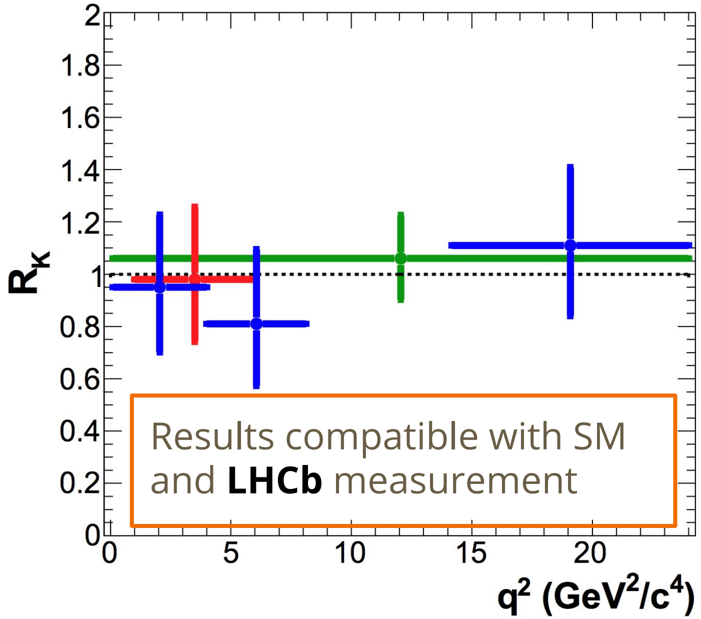
- 3D fit in M_{bc}, ΔE and classifier output (O')



Updated R_K from Belle

arXiv:1908.01848

Measure charged and neutral modes separately and weighted average in q^2 regions: [0.1 , 4.0], [4.0 , 8.12], > 14.18, [1.0 , 6.0], > 0.1



Updated R_K from Belle

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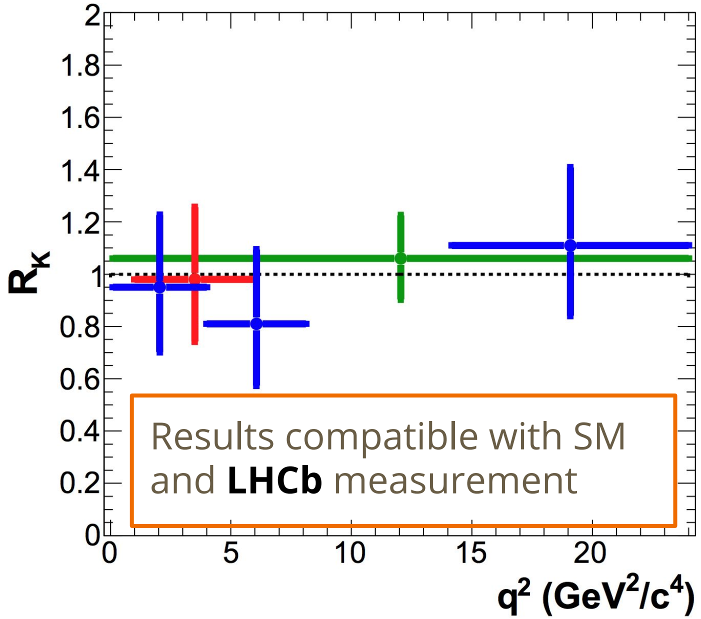
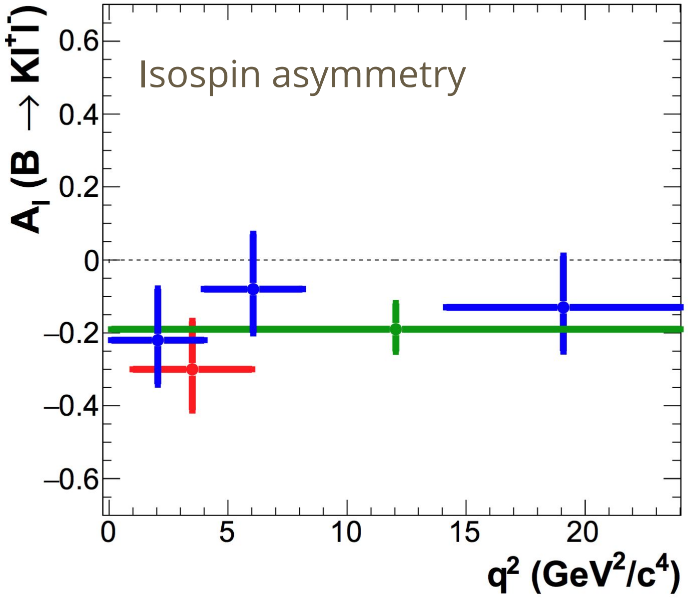
Measure charged and neutral modes separately and weighted average in q^2 regions: [0.1 , 4.0], [4.0 , 8.12], > 14.18, [1.0 , 6.0], > 0.1



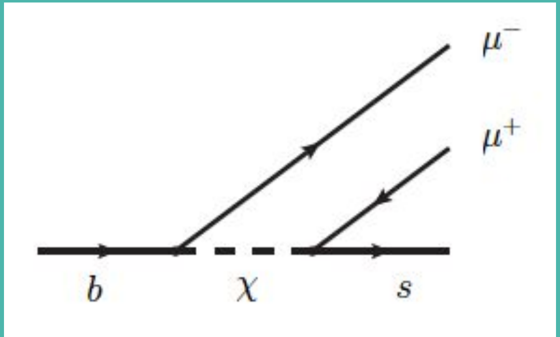
Results compatible with SM and **LHCb** measurement

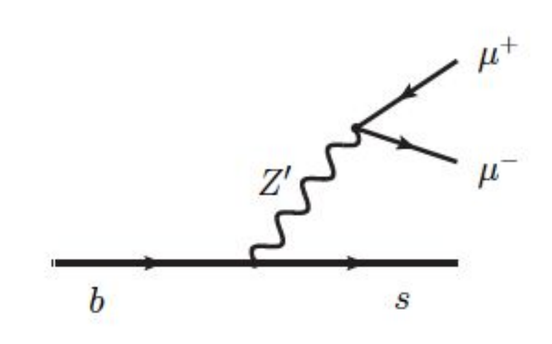


Lepton Flavour Violation searches

LFUV $\longrightarrow$ LFV?

See talks by J. Hisano, F. Archili, M. Blanke





Search for $B_{(s)} \to \tau^{\pm}\mu^{\mp}$ at LHCb

arXiv:1905.06614

Forbidden in the SM, BR up to 10^{-4} in NP scenarios

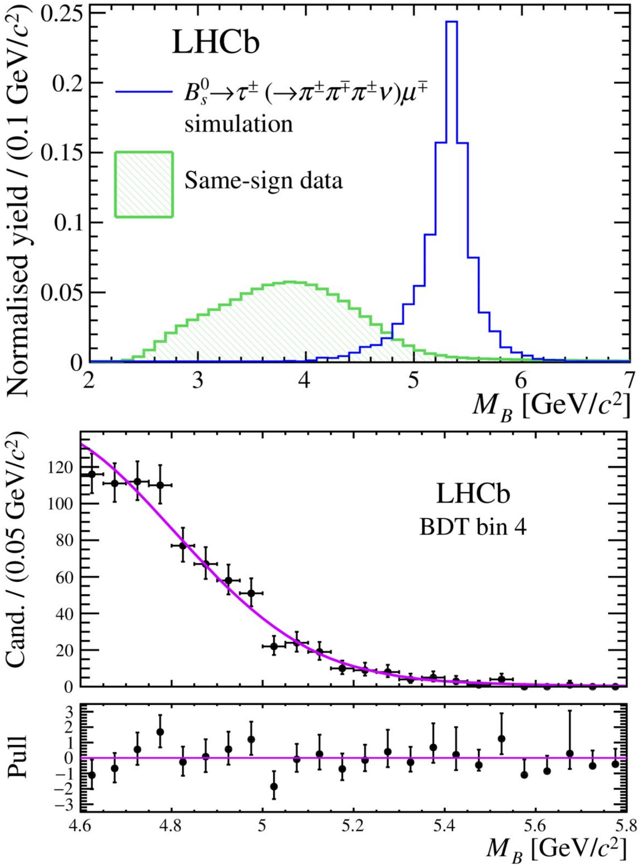
$B(B^0 \to \tau^{\pm}\mu^{\mp}) < 2.2 \times 10^{-5}$ at 90% CL by BaBar
No limit for B_s mode

Search using Run 1 LHCb data (3 fb^{-1}) and hadronic tau decay $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ with kinematic constraints

$B^0 \to D^-(\to K^+\pi^-\pi^-)\pi^+$ used as normalisation and same-sign data as background proxy

No signal excess observed. At 90% CL:

$$BR(B^0 \to \tau^{\pm}\mu^{\mp}) < 1.2 \times 10^{-5}$$
$$BR(B_s \to \tau^{\pm}\mu^{\mp}) < 3.4 \times 10^{-5}$$



Search for $B^+ \to K^+ \mu^\pm e^\mp$ at LHCb

LHCb-PAPER-2019-022

Forbidden in the SM, BR up to 10^{-8} in NP scenarios

$B(B^+ \to K^+ \mu^- e^+) < 9.1 \times 10^{-8}$ at 90% CL and
$B(B^+ \to K^+ \mu^+ e^-) < 13 \times 10^{-8}$ at 90% CL by BaBar

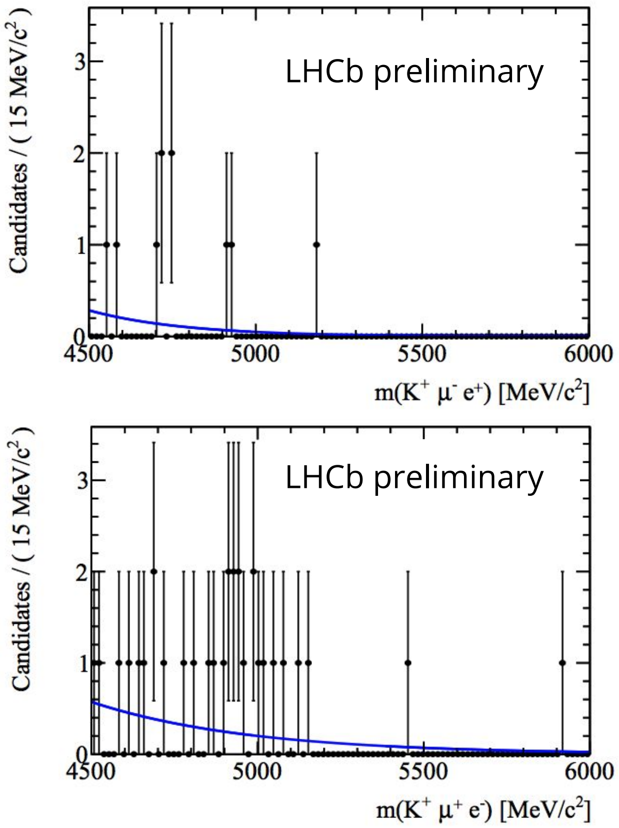
Search using Run 1 LHCb data (3 fb^{-1}) and
$B^0 \to J/\psi K^+$ as normalisation and control mode

Exploit μ triggers, e brem recovery and 2-stage BDT

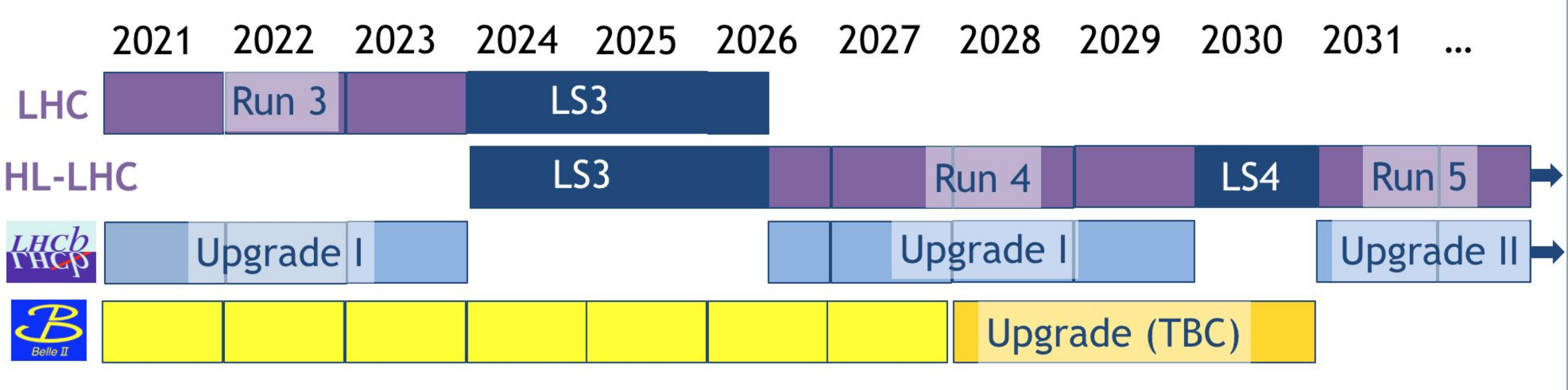
No signal excess observed, BR limits:

$\mathcal{B}/10^{-9}$	90% C. L.	95% C. L.
$B^+ \to K^+ \mu^- e^+$	7.0	9.5
$B^+ \to K^+ \mu^+ e^-$	7.1	9.1

LHCb preliminary



On to the future

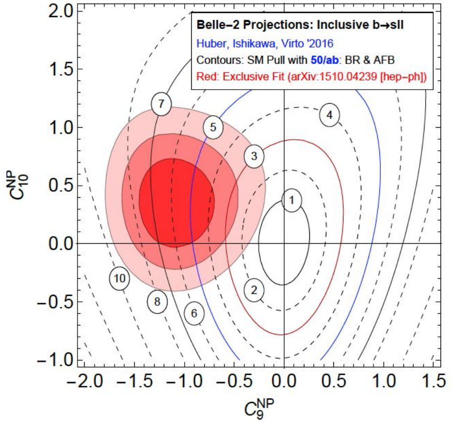


[Belle II Physics Book](#) [LHCB-PUB-2018-009](#)

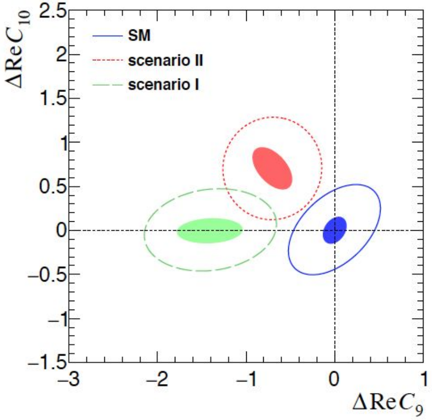
Belle II

LHCb upgrade(s)

Strong constraints on NP in $C_{9,10}$ from $b \to sll$ and on RH currents from $b \to s\gamma$



Observables	Belle $0.71\,\mathrm{ab}^{-1}$	Belle II $50\,\mathrm{ab}^{-1}$
$\mathrm{Br}(B \to X_s\gamma)^{\text{lep-tag}}_{\text{inc}}$	5.3%	3.2%
$\mathrm{Br}(B \to X_s\gamma)^{\text{had-tag}}_{\text{inc}}$	13%	4.2%
$\mathrm{Br}(B \to X_s\gamma)_{\text{sum-of-ex}}$	10.5%	5.7%
$\Delta_{0+}(B \to X_s\gamma)_{\text{sum-of-ex}}$	2.1%	0.63%
$\Delta_{0+}(B \to X_{s+d}\gamma)^{\text{had-tag}}_{\text{inc}}$	9.0%	0.85%
$A_{CP}(B \to X_s\gamma)_{\text{sum-of-ex}}$	1.3%	0.19%



Constraints from LFU observables with $50\ \mathrm{fb}^{-1}$ (dashed) and $500\ \mathrm{fb}^{-1}$ (filled)

γ polarisation	U1 ($50\ \mathrm{fb}^{-1}$)	U2 ($300\ \mathrm{fb}^{-1}$)
$B_s \to \varphi\gamma$	0.07	0.02
$\Lambda_b \to \Lambda^0\gamma$	10%	4%

Summary & conclusions

Rare decays provide stringent tests of NP at large scales

- Interesting tensions in b → sll transitions could be a hint of NP
- Latest results with better precision cannot confirm neither deny them
- Updates with more data and new modes under development
- Crucial to test predictions of potential NP models → LFV
- Complementary constraints on right handed currents from b → sγ

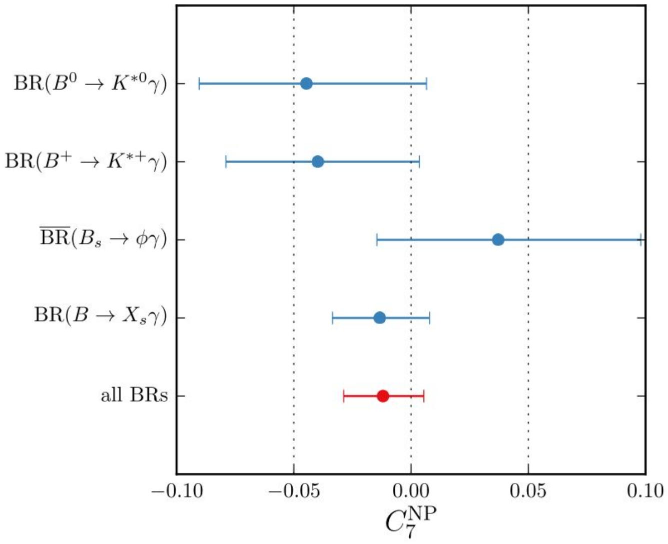
Not covered here:

- results from Atlas and CMS ($B_{(s)} \to \mu^+\mu^-$): see talk by F. Archili
- interpretation of results in terms of NP models: see talk by M. Blanke

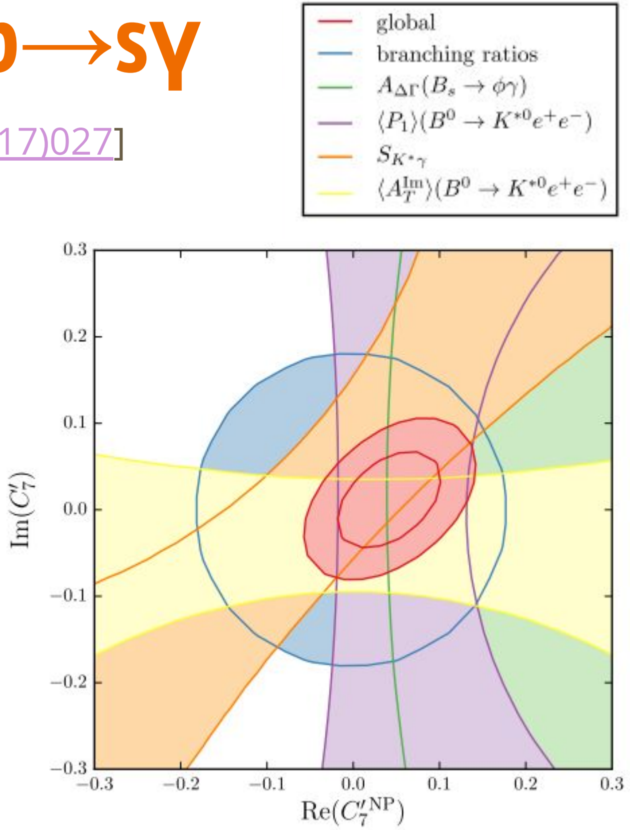
BACK-UP

New Physics constraints from b⟶sγ

Paul & Straub [JHEP04(2017)027]



$$\mathrm{Im}\,\Delta C_7(\mu_b) = -0.027 \pm 0.016 \qquad \text{for } B^0 \to K^*\gamma$$



Phys.Rev.D.99.032012(2019)

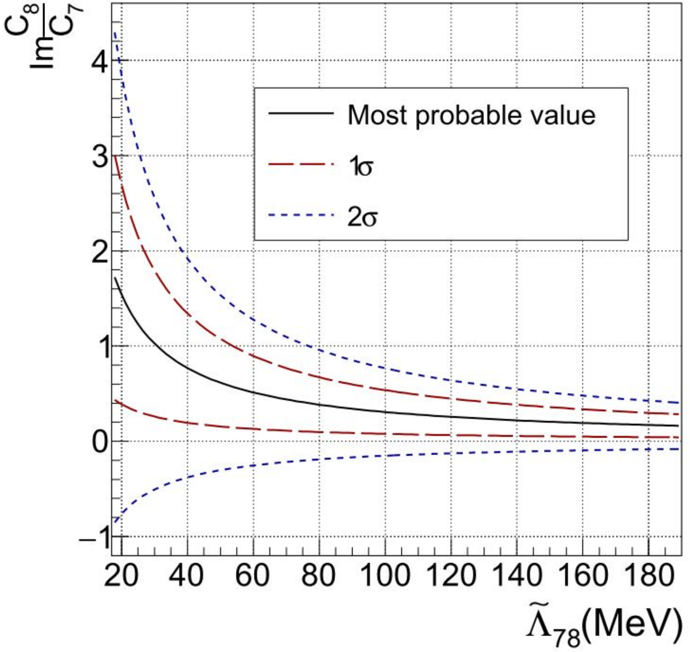
Isospin (Δ_{0-}) and CP (A_{CP}) asymmetry in $B \longrightarrow X_s \gamma$

- Full Belle data
- Inclusive = sum of exclusive

$$\Delta_{0-} = [-0.48 \pm 1.49 \pm 0.97 \pm 1.15]\%$$

$$\frac{\mathcal{B}^{78}_{\mathrm{RP}}}{\mathcal{B}} \simeq (+0.16 \pm 0.50 \pm 0.32 \pm 0.38 \pm 0.05)\%$$

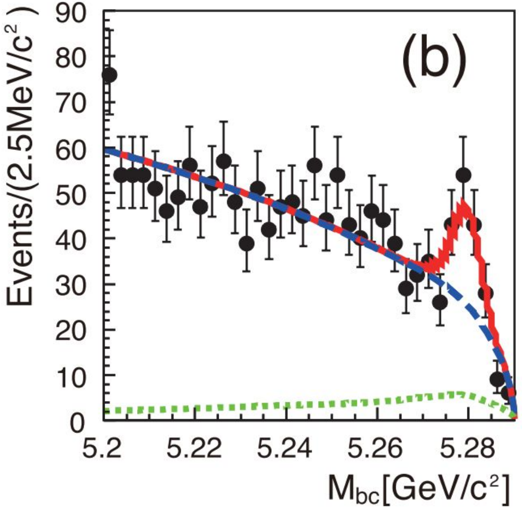
$$\Delta A_{CP} = [+3.69 \pm 2.65 \pm 0.76]\%$$

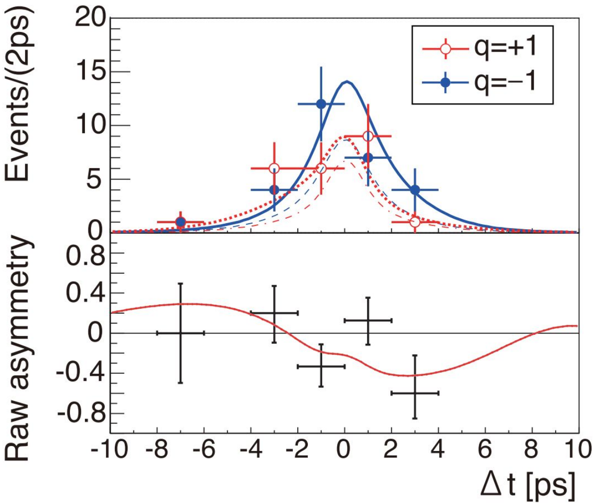


Photon polarization in $B^0 \to K_S \eta \gamma$

Phys.Rev.D.97.092003(2018)

- Full Belle data, $m(K_S\eta) < 2.1\ \mathrm{GeV}/c^2$, inclusive tagging





$$\mathcal{P}(\Delta t) \propto q\,[\mathcal{S}\sin(\Delta m_d \Delta t) + \mathcal{A}\cos(\Delta m_d \Delta t)]$$

$$S_{K_S\eta\gamma} = -1.32 \pm 0.77 \pm 0.36$$
$$\mathcal{A}_{K_S\eta\gamma} = -0.48 \pm 0.41 \pm 0.07$$

Isospin asymmetry in B ⟶ Kll from Belle

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