Anomalies in neutral-current B-decays

The 2022 Conference on Flavor Physics and CP Violation

Dedicated in memory of Sheldon Stone

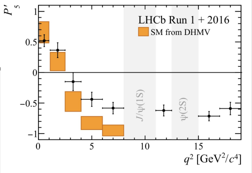
The University of Mississippi

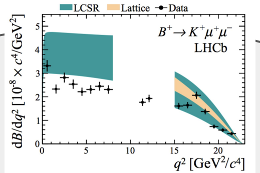
Nico Serra - University of Zurich
On behalf of the LHCb Collaboration

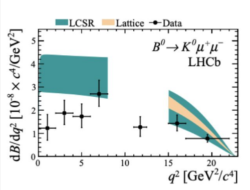
University of Zurich[UZH]

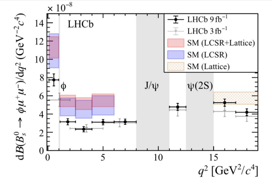
Overview

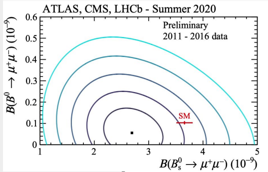
b→sμμ

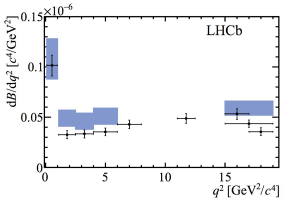




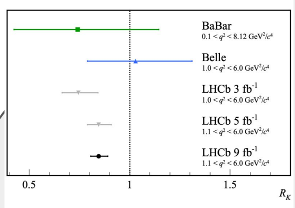


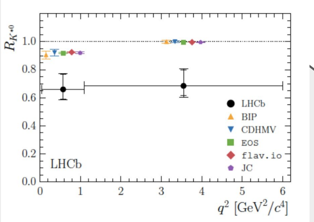


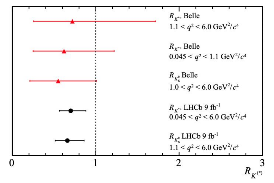


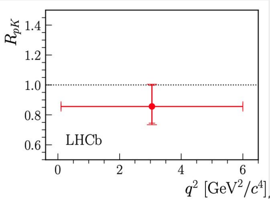


b→sμμ/b→see



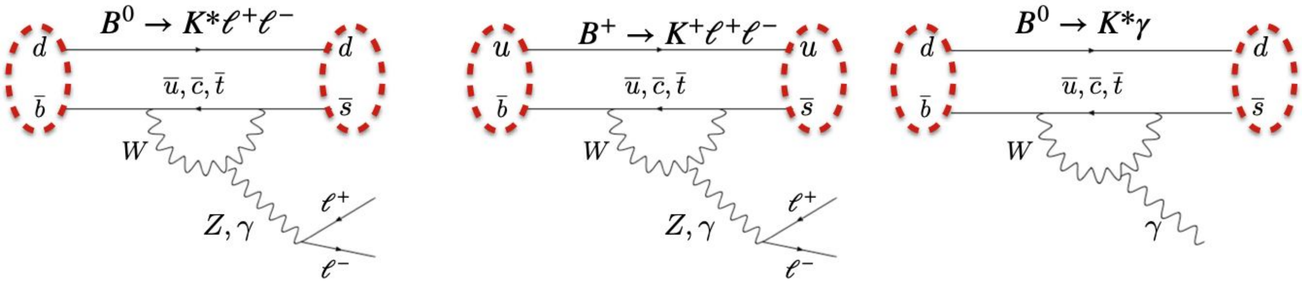




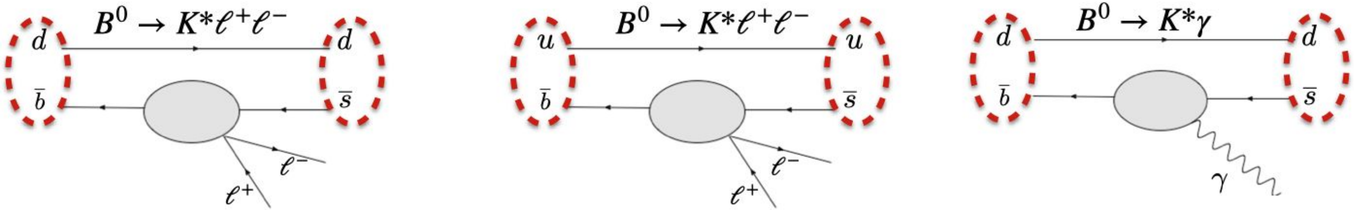


Introduction

Effective Hamiltonian



Use an effective operator approach, similar to Fermi theory of weak interaction



$$\mathscr{A}(i \to f) = < f | \mathscr{H}_{eff} | i >$$

Introduction

Effective Hamiltonian

Local operators

$\langle f|O_i|i\rangle$ Long distance QCD

$$\mathcal{H}_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i \mathcal{C}_i^{(\prime)} \mathcal{O}_i^{(\prime)}$$

Wilson Coefficients
Effective coupling

Introduction

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New Physics can contribute to different WCs depending on its Lorentz structure

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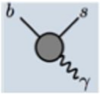
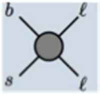
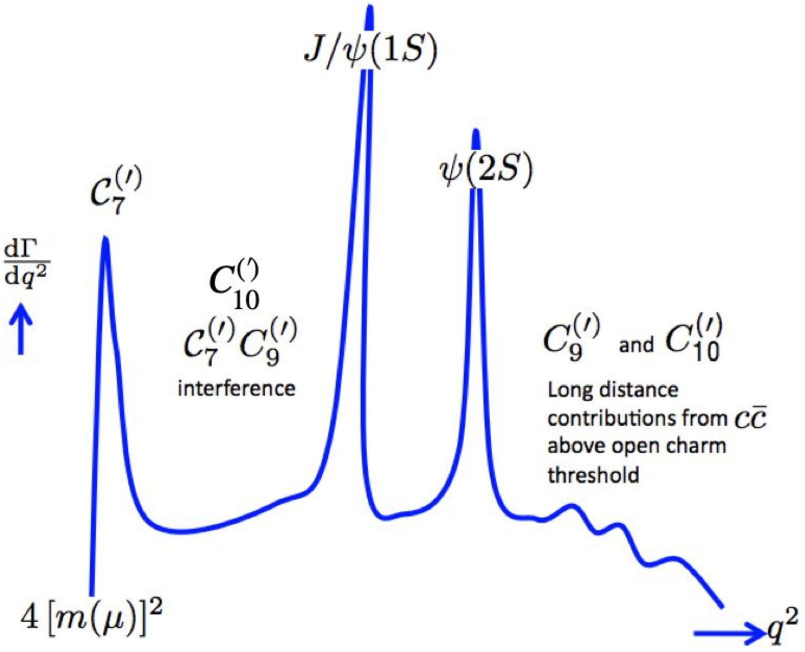




Operator $\mathcal{O}_i$	$B \to K^{*0}\gamma$	$B \to K^{*0}\mu^+\mu^-$	$B \to \mu^+\mu^-$
$\mathcal{O}_7 \sim m_b(\bar{s}_L\sigma_{\mu\nu}b_R)F_{\mu\nu}$	✓	✓	
$\mathcal{O}_9 \sim (\bar{s}b)_{V-A}(\bar{\ell}\ell)_V$		✓	
$\mathcal{O}_{10} \sim (\bar{s}b)_{V-A}(\bar{\ell}\ell)_A$		✓	✓
$\mathcal{O}_{S,P} \sim (\bar{s}b)_{S+P}(\bar{\ell}\ell)_{S,P}$			✓

Angular analysis of B→K*(→ Kπ)μμ



$$\mathscr{A}(i \rightarrow f) = \langle f | \mathscr{H}_{eff} | i \rangle$$

- Six complex amplitudes
- Amplitudes labelled according to the K* polarization and the L/R chirality of the di-muon

$$A_0^{L,R} \propto [C^+_{9\mp10} A_{12} + C^+_7 T_{23}]$$
$$A_\parallel^{L,R} \propto [C^-_{9\mp10} A_1 + C^-_7 T_2]$$
$$A_\perp^{L,R} \propto [C^-_{9\mp10} V + C^-_7 T_1]$$

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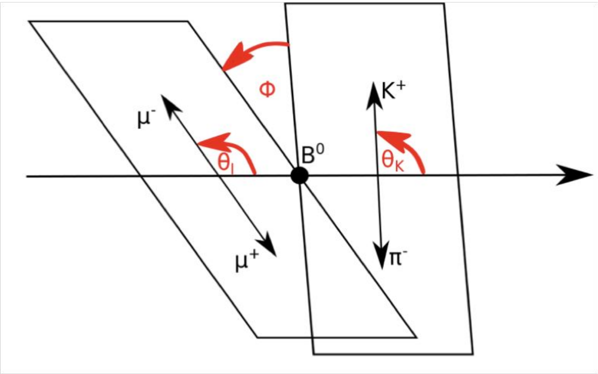
Angular analysis of B→K*(→ Kπ)μμ



- Differential decay rate described by 3 angles (θ_l , θ_K , Φ) and the di-muon invariant mass squared (q^2)
- Angular observables bilinear combinations of the 6 complex amplitudes
- P_5' is the best known due to the measured discrepancy

$$\frac{1}{\Gamma}\frac{d^3(\Gamma+\bar{\Gamma})}{d\cos\theta_\ell\, d\cos\theta_K\, d\phi} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell$$
$$- F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi +$$
$$\sqrt{F_L(1-F_L)}P_5'\sin 2\theta_K\sin\theta_\ell\cos\phi + \frac{4}{3}A_{FB}\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi +$$
$$S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]$$

Angular analysis of B→K*(→ Kπ)μμ

Several observables proposed references

At large recoil (low-q^2)

$$R_1 = \frac{T_1}{V} \sim 1$$
$$R_2 = \frac{T_2}{A_1} \sim 1$$
$$R_3 = \frac{T_{23}}{A_{12}} \sim \frac{q^2}{m_B^2}$$

P-basis (P_1,...,P_8) FF appears in the numerator and in the denominator

$$P_5' \propto \frac{\mathcal{R}(A_0 A_\perp)}{\sqrt{|A_0|^2 \times |A_\perp|^2}}$$

J. Matias et al. JHEP 04 (2012) 104

Using full form-factors with correlations similar results are obtained with the (S_i) basis

Altmannshofer et al. JHEP 01 (2009) 019

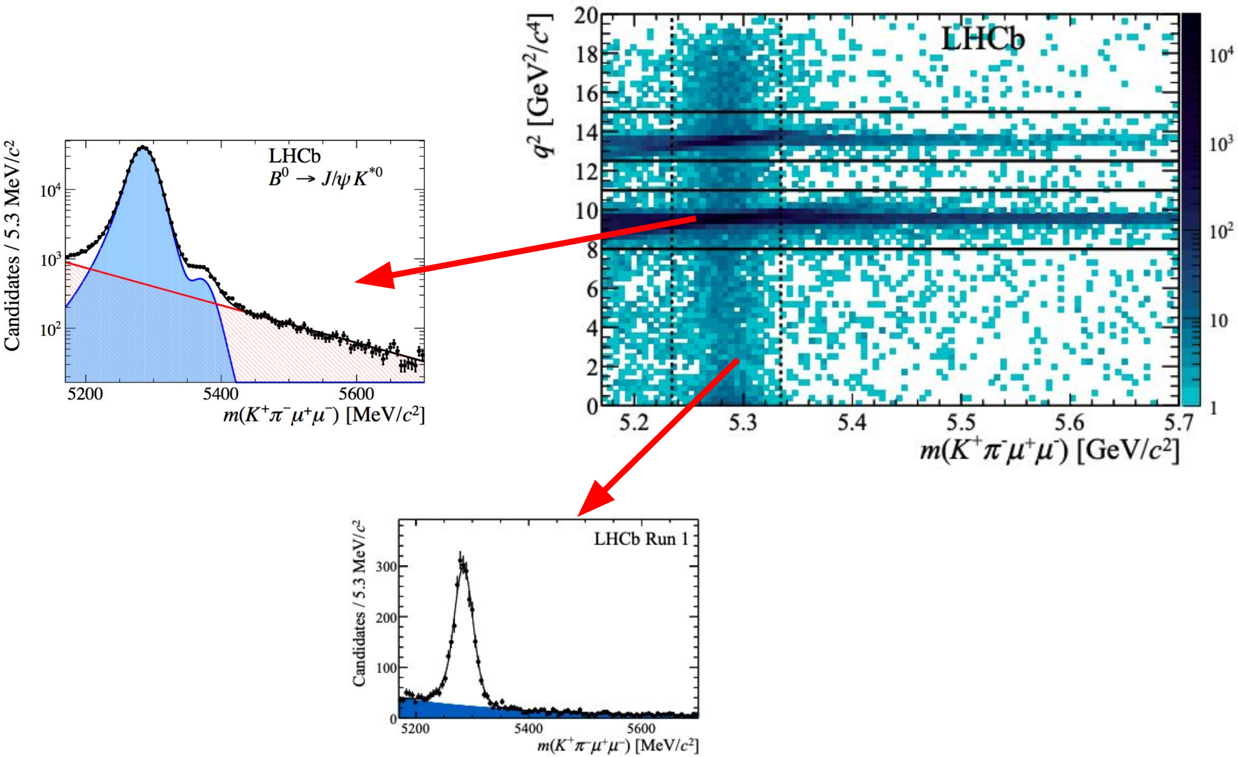
$$S_i = \frac{I_i + \bar{I}_i}{d\Gamma/dq^2 + d\bar{\Gamma}/dq^2}$$

Other observables have been suggested

Becirevic et al., Nucl.Phys.B 854 (2012) 321-339
Bobeth et al., JHEP 07 (2010) 098
Lunghi, Soni, JHEP 11 (2010) 121
and references therein

Angular analysis of $B \to K^*(\to K\pi)\mu\mu$

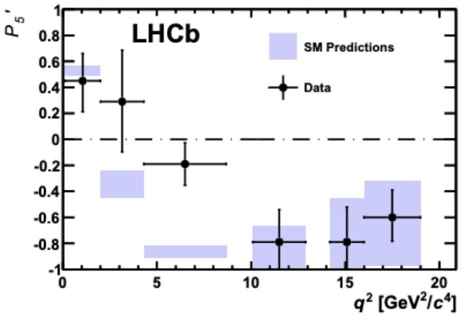
LHCb Coll, Phys.Rev.Lett. 125 (2020) 1, 011802



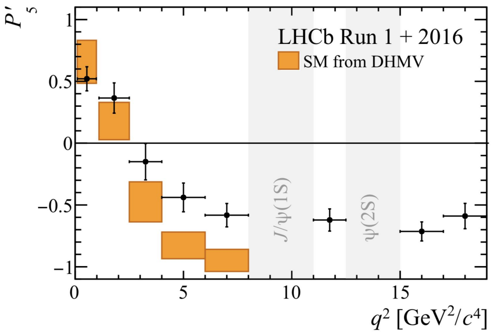
b→sμμ

Angular analysis of B→K*(→ Kπ)μμ

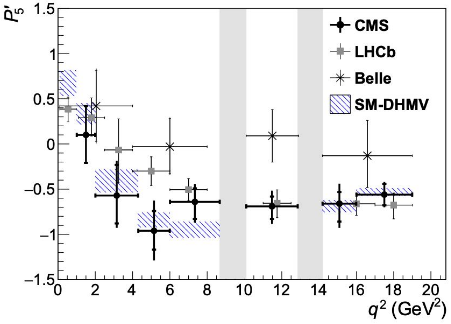
- Deviations from SM predictions observed by LHCb in P_5' (and other angular observables) in the decay B→K*μμ (2013, $1fb^{-1}$)
- Confirmed by followed up analyses of B→K*μμ (2015, $3fb^{-1}$ and 2019, $5fb^{-1}$)



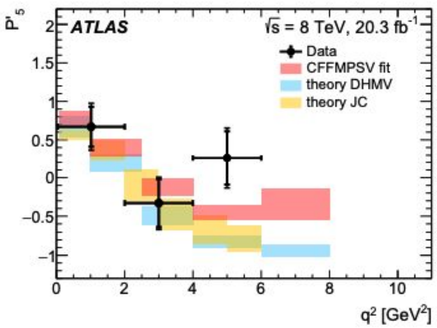
Phys.Rev.Lett. 111 (2013) 191801



Phys.Rev.Lett. 125 (2020) 1, 011802



Phys.Lett.B 781 (2018) 517-541

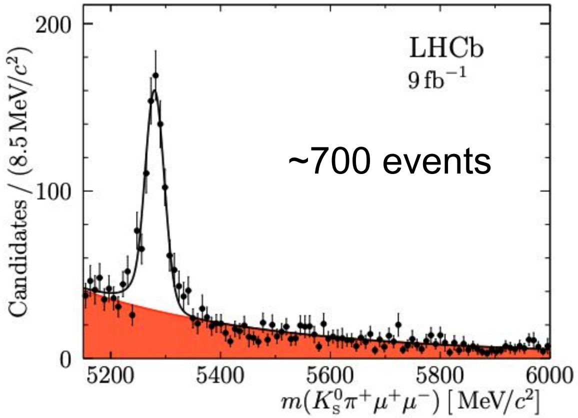


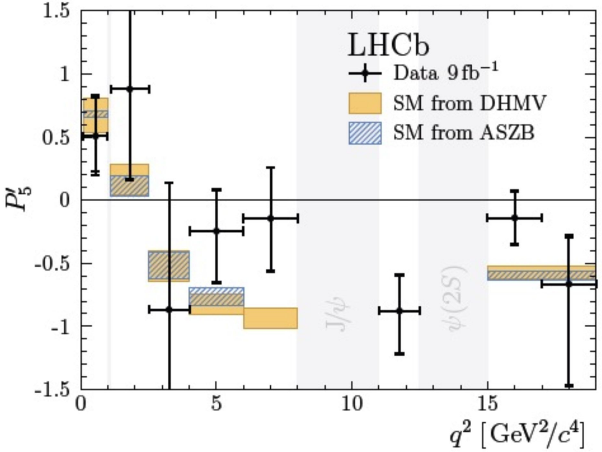
JHEP 10 (2018) 047

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

LHCb Coll, Phys.Rev.Lett. 126 (2021) 16, 161802

- Angular analysis of $B^+ \to K^{*+}\mu\mu$ in very good agreement with the tension observed in $B \to K^*\mu\mu$
- Different systematics and background wrt $B \to K^*\mu\mu$

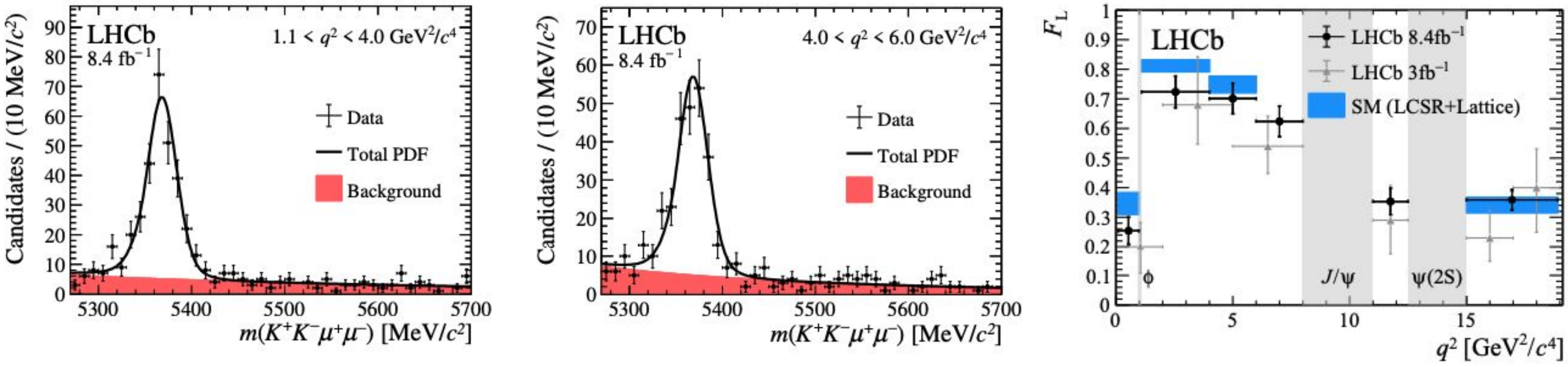




Angular analysis of $B_s \to \Phi\mu\mu$

LHCb Coll, JHEP 09 (2015) 179

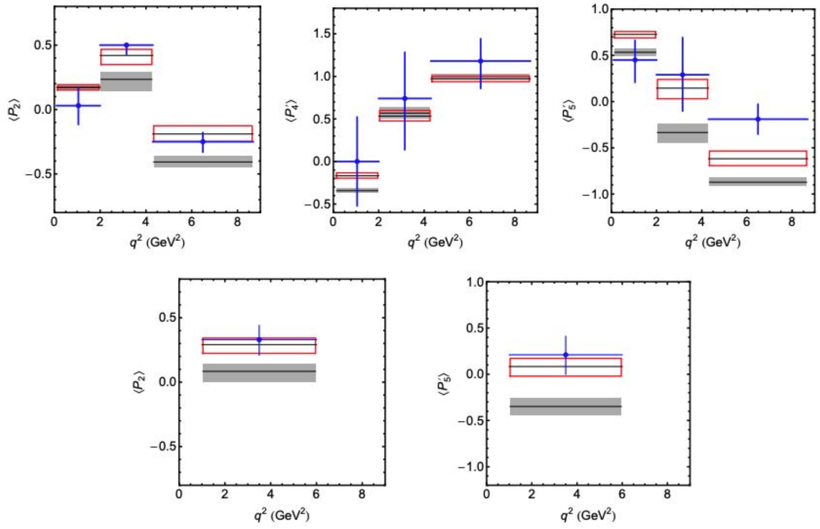
- Angular analyses of the decay $B_s \to \Phi\mu\mu$ also shows discrepancies wrt SM predictions
- No access to P_5' or A_{FB} since $B_s \to \Phi\mu\mu$ is not self-tagging



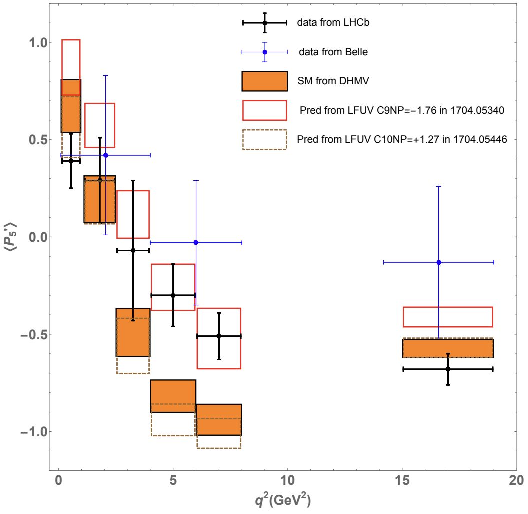
Theory explanations of the B→K*μμ anomaly

- Discrepancies in the angular distribution of B→K*μμ best explained by shift in C_9

Decotes-Genon, Matias, Virto Phys.Rev.D 88 (2013) 074002



Capdevilla et al., JHEP 01 (2018) 093



See also *Altmannshofer, Straub Eur.Phys.J.C 73 (2013) 2646*, Beaujean et al., *Eur.Phys.J.C 74 (2014) 2897*, Hurth et al., *JHEP* 04 (2014) 097

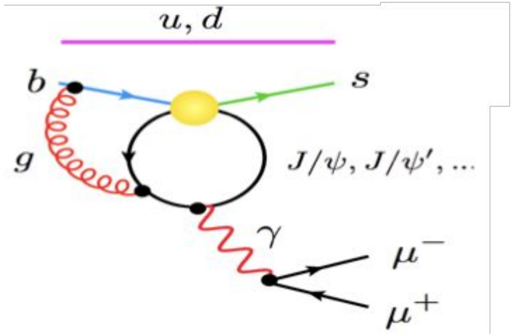
b→sμμ

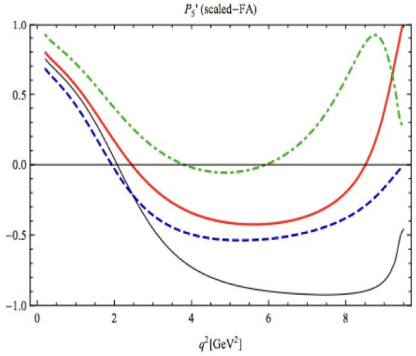
Theory explanations of the B→K*μμ anomaly

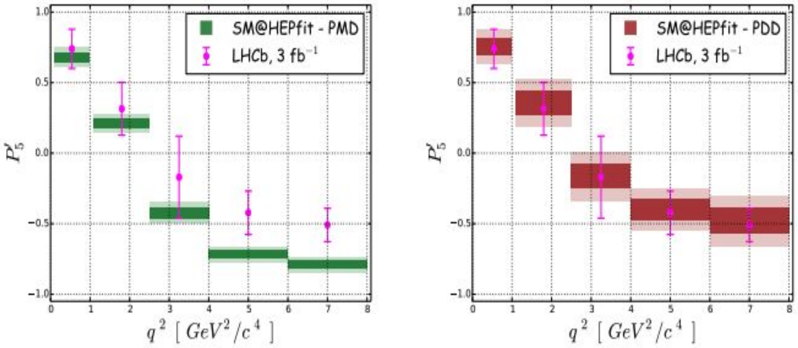
- This can be interpreted either as NP or as larger-than-expected charm loop

[Lyon, Zwicky arXiv:1406.0566](#)

[*Ciuchini et al., JHEP 06 (2016) 116*](#)







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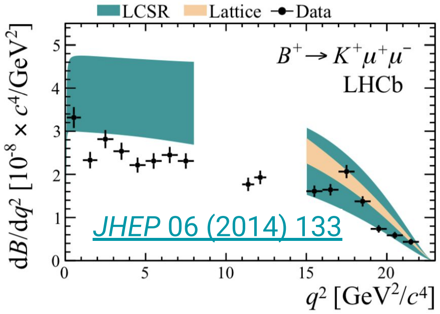
Branching ratio measurements of b→sμμ

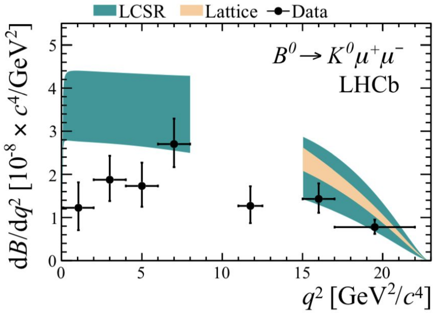
- LHCb observes low values of branching ratios for b→sμμ transitions
- Can be explained by shift in C_9 or $C_{9\,/\,10}$ simultaneously

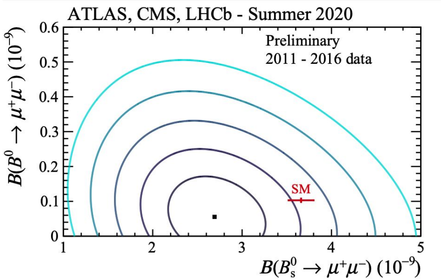
LHCb Coll, Phys. Rev. Lett. **128**, 041801

LHCb Coll., Phys.Rev.D 105 (2022) 1, 012010



JHEP 06 (2014) 133

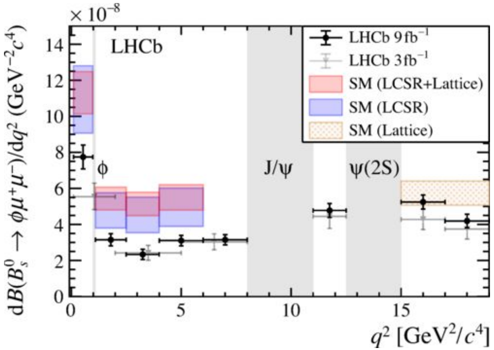




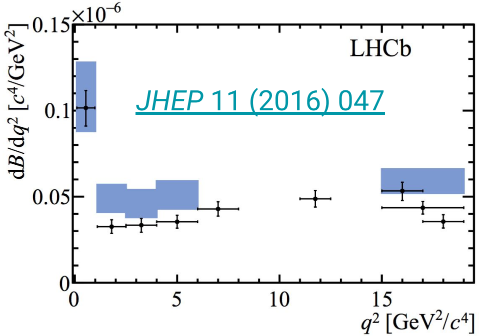
$$\mathscr{B}(B^0_s \to \mu^+\mu^-) = (3.09^{+0.46+0.15}_{-0.43-0.11}) \times 10^{-9}$$

$$\mathscr{B}(B^0 \to \mu^+\mu^-) < 2.6 \times 10^{-10}$$

CMS-PAS-BPH-20-003
LHCb-CONF-2020-002
ATLAS-CONF-2020-049



Phys.Rev.Lett. 127 (2021) 15, 151801



JHEP 11 (2016) 047

- Waiting for B_s→μμ updates since C_{10} is theoretically clean

- Possibility to extract C_{10} also from B→K*μμ angular distributions

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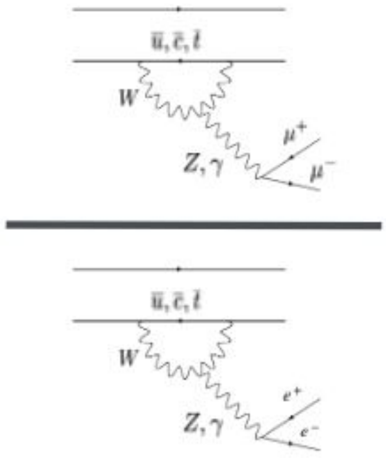
LFU tests in rare decays

- Test of LFU are sensitive to those models that have a hierarchical coupling with lepton families
- LFU R-ratios have small theory uncertainty (<1%)

Bordone et al., Eur.Phys.J.C 76 (2016) 8, 440
Isidori, Zwicky JHEP 12 (2020) 104

$$R_X = \frac{\int_{q_{\min}}^{q_{max}} \frac{d\Gamma(H_b \to X_s \mu\mu)}{dq^2}}{\int_{q_{\min}}^{q_{max}} \frac{d\Gamma(H_b \to X_s ee)}{dq^2}} =$$



$= 1$

SM

b→sμμ/b→see

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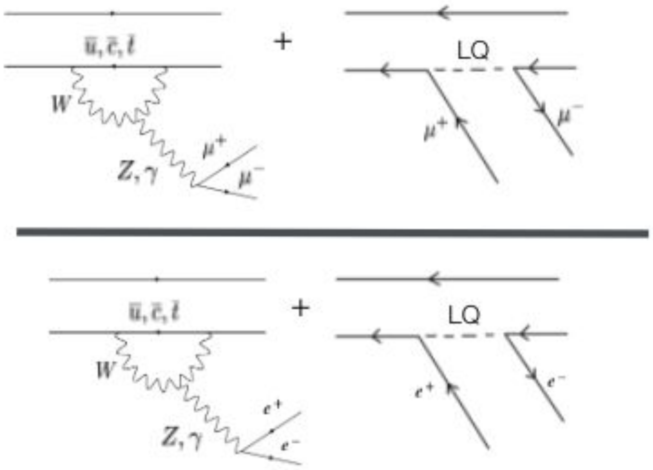
[Bordone et al., Eur.Phys.J.C 76 (2016) 8, 440](#)
[Isidori, Zwicky JHEP 12 (2020) 104](#)

$$R_X = \frac{\int_{q_{\min}}^{q_{max}} \frac{d\Gamma(H_b \to X_s \mu\mu)}{dq^2}}{\int_{q_{\min}}^{q_{max}} \frac{d\Gamma(H_b \to X_s ee)}{dq^2}} =$$



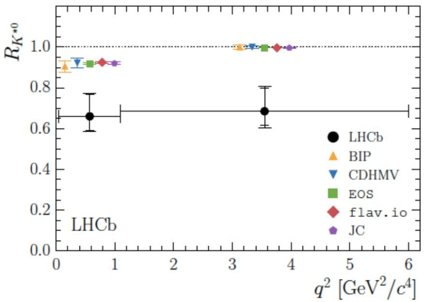
$\neq 1$ possible NP

b→sμμ/b→see

LFU tests in rare decays

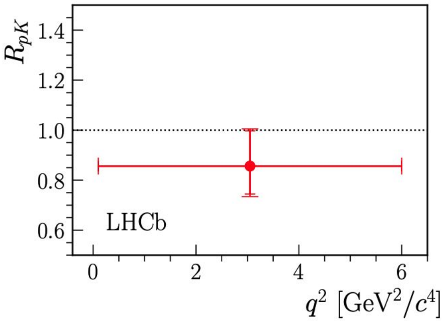
- Since 2014 LHCb measured deviations from LFU in b→sll transitions
- Still statistically limited but all measurements of b→sμμ/b→see ratios are below 1.0 (SM prediction)

$B^0 \to K^* \ell\ell$



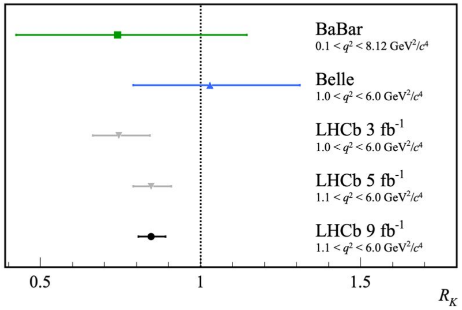
[Phys.Rev.Lett. 125 (2020) 1, 011802](#)

$\Lambda_b \to pK\ell\ell$



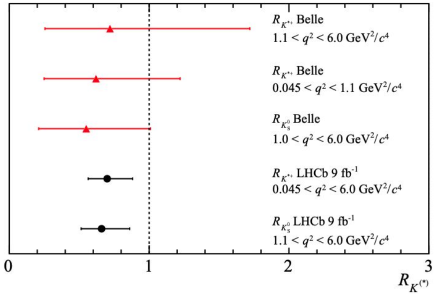
[JHEP 05 (2020) 040](#)

$B^+ \to K^+ \ell\ell$



[Nature Phys. 18 (2022) 3, 277-282](#)

$B^+ \to K^{*+} \ell\ell,\ B^0 \to K_S \ell\ell$



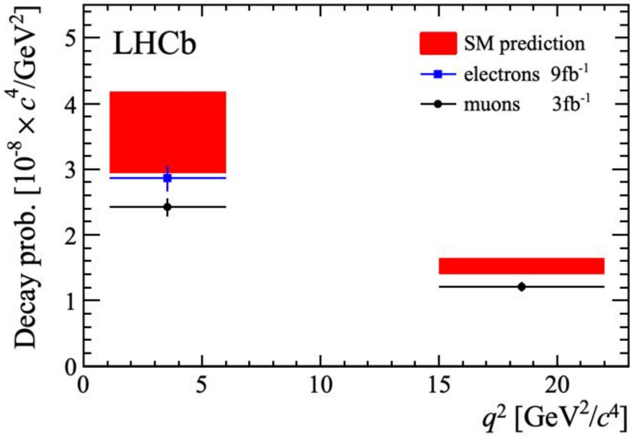
[Phys.Rev.Lett. 128 (2022) 19, 191802](#)

[See talk by Silvia Ferreres Solè (parallel session on Tuesday morning)](#)

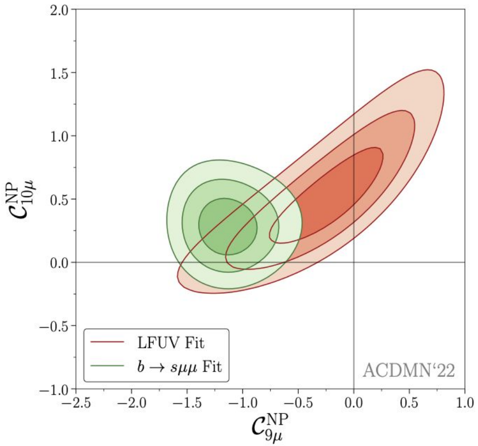
b→sll anomalies

Are b→sμμ and LFUV anomalies connected?

Nature Phys. 18 (2022) 3, 277-282



Courtesy of Quim Matias
Eur.Phys.J.C 82 (2022) 4, 326



In agreement with other fitting groups (Flavour Anomaly Workshop 21):

Altmannshofer, Stangl Eur.Phys.J.C 81 (2021) 10, 952

Ciuchini et al., Phys.Rev.D 103 (2021) 1, 015030

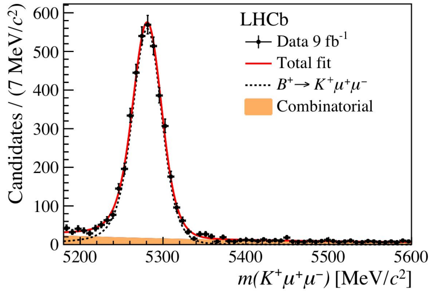
Hurth et al., Phys.Lett.B 824 (2022) 136838

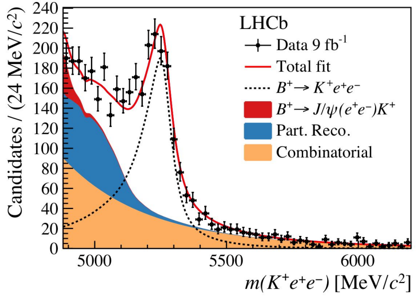
- LFU measurements seem to point to deficit of muons with respect to electrons
- This is numerically consistent with the anomalies measured in b→sμμ transitions
- Electrons are found to be consistent with SM

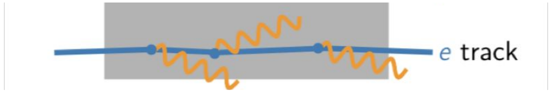
Theory VS experiments

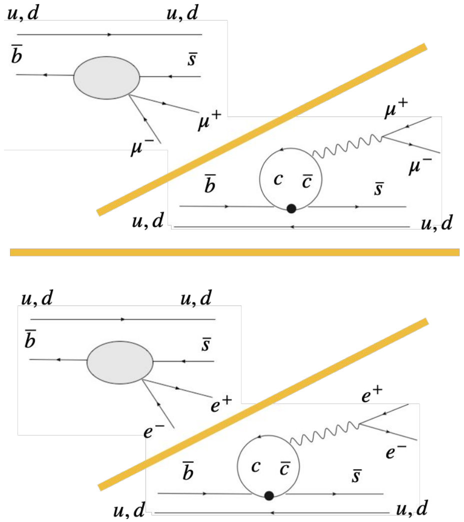
Muon vs electrons

Nature Phys. 18 (2022) 3, 277-282









EPJC 76 (2016) 8, 440

$= 1.00 \pm 0.01$

- Electron mode less efficient
- Much worse mass resolution
- More difficult charmonia vetos
- More difficult background
- More difficult calibration (alleviated by double ratio)

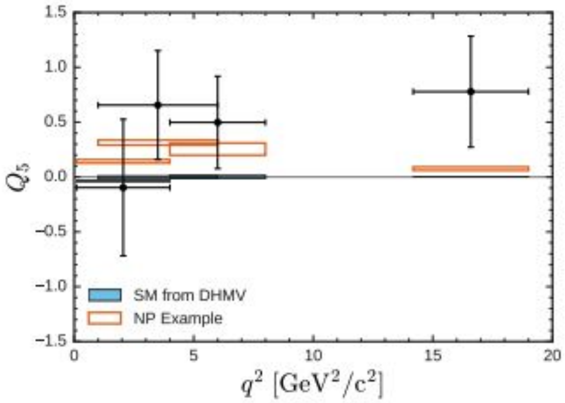
Experimental challenges

Measuring more LFU R-ratios

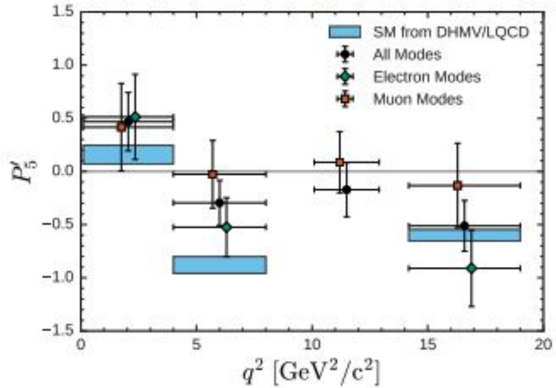
Important to perform more LFU measurements with different systematics

- R_K, R_{K^*} at high-q^2 (experimentally challenging)
- $R_{K\pi}$=Br(B→Kπ ee)/Br(B→Kπ μμ), $R_{K\pi\pi}$=Br(B→Kππ ee)/Br(B→Kππ μμ) (see *Isidori et al., Phys.Lett.B 830 (2022) 137151* and *Hiller et al., JHEP 02 (2015) 055*)
- LFU test of angular observables in B→K*ll (see *Matias et al., JHEP 10 (2016) 075*)

$$Q_5 = P_5'(B^0 \to K^*\mu\mu) - P_5'(B^0 \to K^*ee)$$

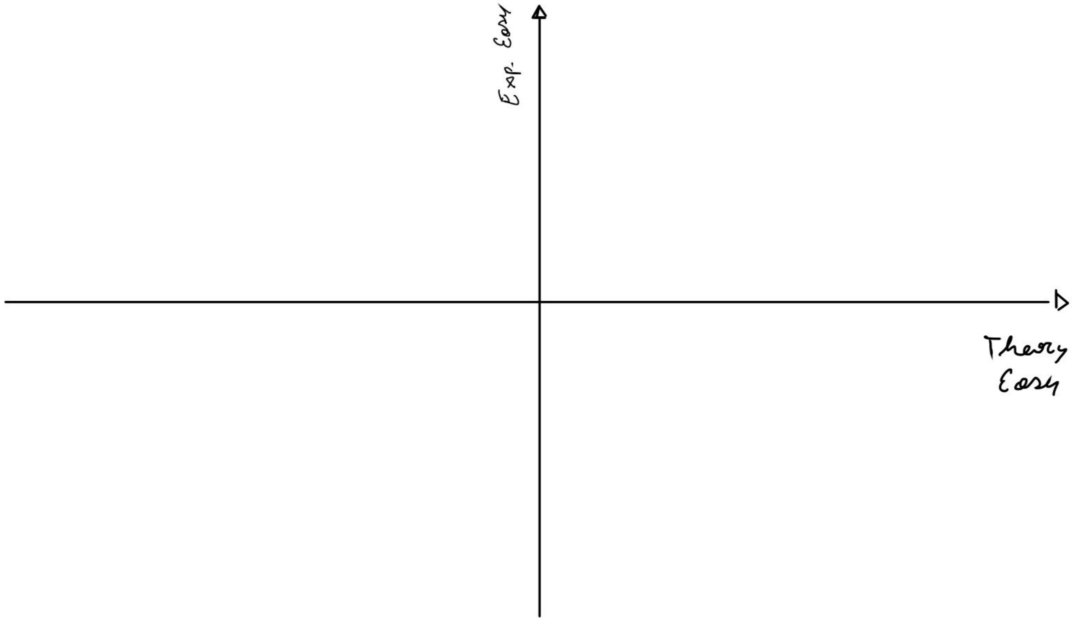


Belle Coll., Phys.Rev.Lett. 118 (2017) 11, 111801



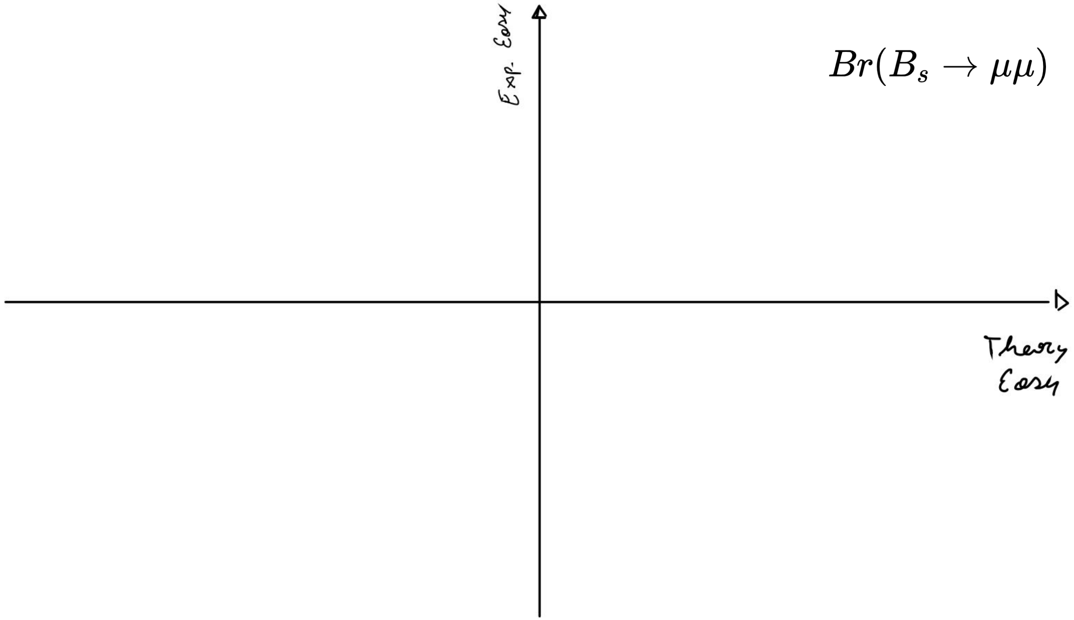
Theory VS experiments

Theory VS Experimentally easy



Theory VS experiments

Theory VS Experimentally easy



$Br(B_s \to \mu\mu)$

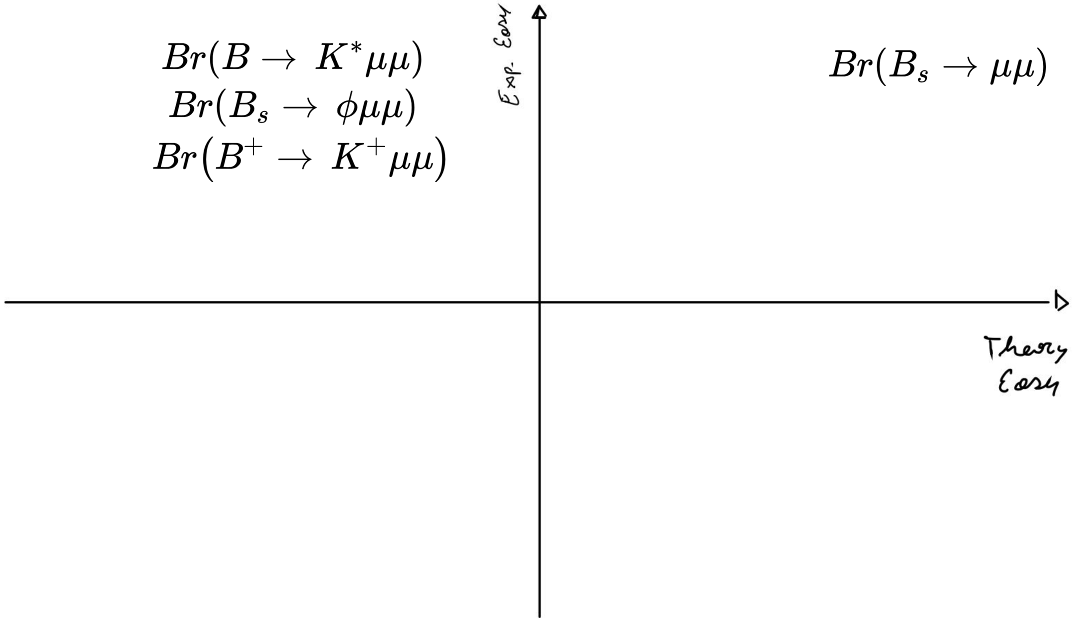
Theory VS experiments

University of Zurich[UZH]

Theory VS Experimentally easy

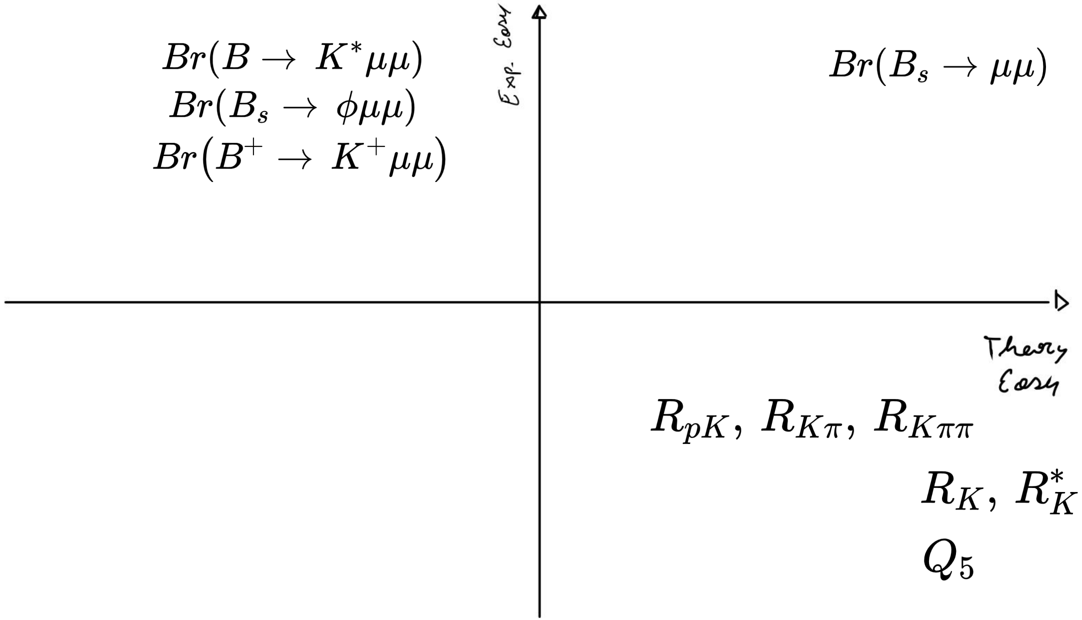
$Br(B \to K^* \mu\mu)$
$Br(B_s \to \phi\mu\mu)$
$Br(B^+ \to K^+ \mu\mu)$

$Br(B_s \to \mu\mu)$



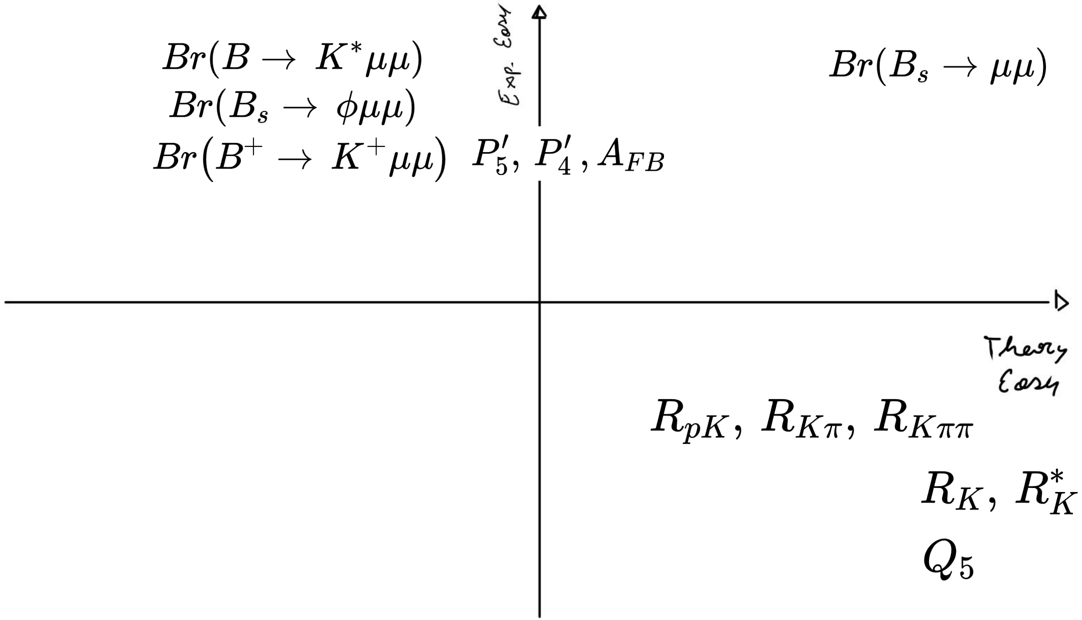
Theory VS experiments

Theory VS Experimentally easy



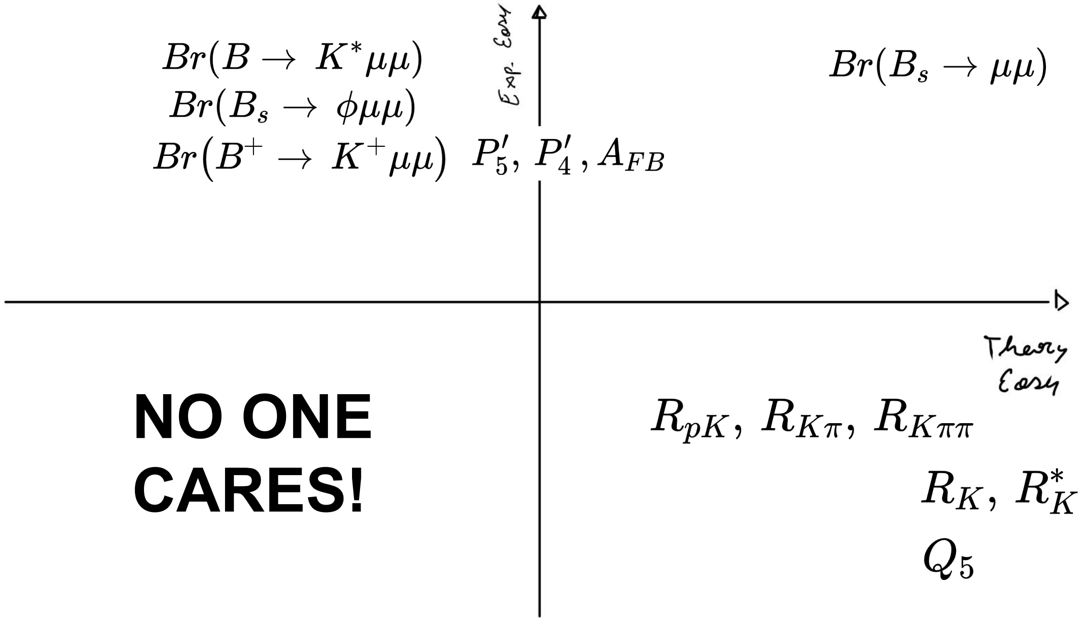
Theory VS experiments

Theory VS Experimentally easy



Theory VS experiments

Theory VS Experimentally easy



Measuring the charm loop in Experiment

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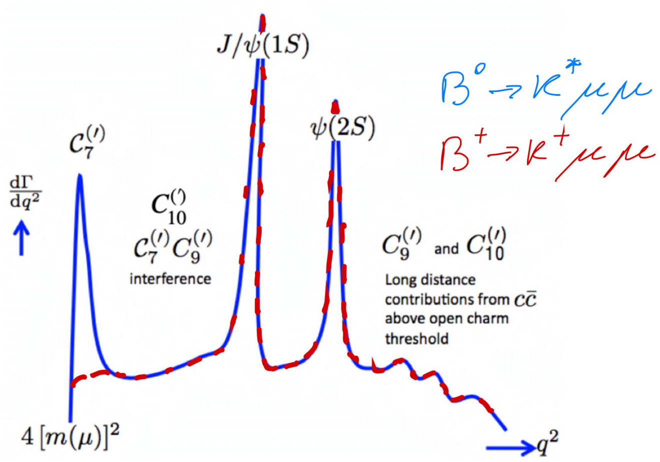
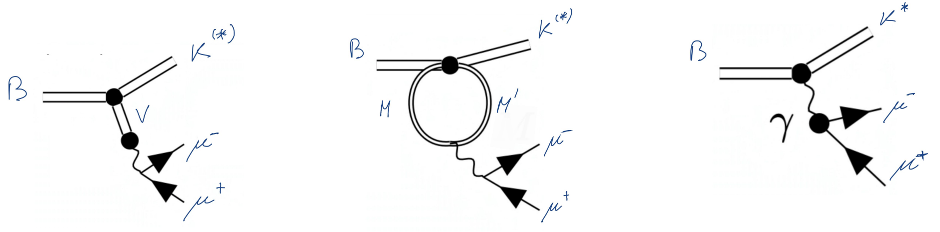
General idea





- Q^2 spectrum has theory uncertainties from form-factors and hadronic long-distance contributions
- Form-factors well described by lattice QCD (ailey et al., *Phys.Rev.D* 93 (2016) 2, 025026) and LC sum rules (Gubernari et al., *JHEP* 01 (2019) 150)
- Far from resonances, estimation using perturbative bounds (Beneke et al., *Nucl.Phys.B* 612 (2001) 25-58, Khodjamirian et al., *JHEP* 09 (2010) 089)
- Reliable description of the whole spectrum needs a hybrid data-driven theory approach

Measuring the charm loop in Experiment

University of Zurich[UZH]

$B^+ \rightarrow K^+\mu\mu$

$$\frac{d\Gamma}{dq^2} = \frac{\alpha_{\rm em}^2 G_F^2 |V_{tb}V_{ts}^*|^2}{128\,\pi^5}\kappa(q^2)\beta(q^2)\left\{\frac{2}{3}\kappa^2(q^2)\beta^2(q^2)\left|\mathcal{C}_{10}^{\mu} f_+(q^2)\right|^2 + \frac{m_\mu^2(m_B^2 - m_K^2)^2}{q^2\, m_B^2}\left|\mathcal{C}_{10}^{\mu} f_0(q^2)\right|^2\right.$$

$$\left. +\kappa^2(q^2)\left[1 - \frac{1}{3}\beta^2(q^2)\right]\left|\mathcal{C}_9^{\mu} f_+(q^2) + 2\mathcal{C}_7\frac{m_b + m_s}{m_B + m_K} f_T(q^2)\right|^2\right\}$$

Measuring the charm loop in Experiment

University of Zurich[UZH]

$B^+ \to K^+\mu\mu$

lepton mass

phase space

$$\frac{d\Gamma}{dq^2} = \frac{\alpha_{em}^2 G_F^2 |V_{tb}V_{ts}^*|^2}{128\,\pi^5} \kappa(q^2)\beta(q^2)\left\{\frac{2}{3}\kappa^2(q^2)\beta^2(q^2)\left|\mathcal{C}_{10}^{\mu} f_+(q^2)\right|^2 + \frac{m_\mu^2(m_B^2-m_K^2)^2}{q^2\,m_B^2}\left|\mathcal{C}_{10}^{\mu} f_0(q^2)\right|^2\right.$$

$$\left.+\kappa^2(q^2)\left[1-\frac{1}{3}\beta^2(q^2)\right]\left|\mathcal{C}_9^{\mu} f_+(q^2) + 2\mathcal{C}_7\frac{m_b+m_s}{m_B+m_K} f_T(q^2)\right|^2\right\}$$

Measuring the charm loop in Experiment

University of Zurich[UZH]

$B^+ \to K^+\mu\mu$

form-factors

$$\frac{d\Gamma}{dq^2} = \frac{\alpha_{em}^2 G_F^2 |V_{tb}V_{ts}^*|^2}{128\,\pi^5}\kappa(q^2)\beta(q^2)\left\{\frac{2}{3}\kappa^2(q^2)\beta^2(q^2)\left|C_{10}^{\mu} f_+(q^2)\right|^2 + \frac{m_\mu^2(m_B^2 - m_K^2)^2}{q^2\,m_B^2}\left|C_{10}^{\mu} f_0(q^2)\right|^2 \right.$$

$$\left. +\kappa^2(q^2)\left[1 - \frac{1}{3}\beta^2(q^2)\right]\left|C_9^{\mu} f_+(q^2) + 2C_7\frac{m_b + m_s}{m_B + m_K} f_T(q^2)\right|^2\right\}$$

Measuring the charm loop in Experiment

$B^+ \rightarrow K^+\mu\mu$

Wilson Coefficients

$$\frac{d\Gamma}{dq^2} = \frac{\alpha_{em}^2 G_F^2 |V_{tb}V_{ts}^*|^2}{128\,\pi^5}\kappa(q^2)\beta(q^2)\left\{\frac{2}{3}\kappa^2(q^2)\beta^2(q^2)\left|\mathcal{C}_{10}^{\mu} f_+(q^2)\right|^2 + \frac{m_\mu^2(m_B^2 - m_K^2)^2}{q^2\, m_B^2}\left|\mathcal{C}_{10}^{\mu} f_0(q^2)\right|^2 + \kappa^2(q^2)\left[1 - \frac{1}{3}\beta^2(q^2)\right]\left|\mathcal{C}_9^{\mu} f_+(q^2) + 2\mathcal{C}_7 \frac{m_b + m_s}{m_B + m_K} f_T(q^2)\right|^2\right\}$$

Measuring the charm loop in Experiment

University of Zurich[UZH]

$B^+ \to K^+\mu\mu$

$$\frac{d\Gamma}{dq^2} = \frac{\alpha_{em}^2 G_F^2 |V_{tb}V_{ts}^*|^2}{128\,\pi^5}\kappa(q^2)\beta(q^2)\left\{\frac{2}{3}\kappa^2(q^2)\beta^2(q^2)\left|C_{10}^\mu f_+(q^2)\right|^2 + \frac{m_\mu^2(m_B^2 - m_K^2)^2}{q^2\,m_B^2}\left|C_{10}^\mu f_0(q^2)\right|^2\right.$$

$$\left. + \kappa^2(q^2)\left[1 - \frac{1}{3}\beta^2(q^2)\right]\left|C_9^\mu f_+(q^2) + 2C_7\frac{m_b + m_s}{m_B + m_K}f_T(q^2)\right|^2\right\}$$

Long distance hadronic contribution (including resonances) goes here: $C_9^\mu \to C_9^{\mu,eff}(q^2) = C_9^\mu + Y(q^2)$

Measuring the charm loop in Experiment

The structure of C_9

Cornella et al., Eur.Phys.J.C 80 (2020) 12, 1095

$$\mathcal{C}_9^{\mu,\mathrm{eff}}(q^2) = \mathcal{C}_9^{\mu} + Y_{c\bar{c}}^{(0)} + \Delta Y_{c\bar{c}}^{1\mathrm{P}}(q^2) + \Delta Y_{c\bar{c}}^{2\mathrm{P}}(q^2) + Y_{\mathrm{light}}^{1\mathrm{P}}(q^2) + Y_{\tau\bar{\tau}}(q^2)$$

Measuring the charm loop in Experiment

University of Zurich[UZH]

The structure of C_9

Cornella et al., Eur.Phys.J.C 80 (2020) 12, 1095

$$Y_{c\bar{c}}^{(0)} \approx -0.10 \pm 0.05$$

Khodjamirian, Mannel, Wang JHEP 02 (2013) 010

$$C_9^{\mu,\text{eff}}(q^2) = C_9^{\mu} + Y_{c\bar{c}}^{(0)} + \Delta Y_{c\bar{c}}^{1\text{P}}(q^2) + \Delta Y_{c\bar{c}}^{2\text{P}}(q^2) + Y_{\text{light}}^{1\text{P}}(q^2) + Y_{\tau\bar{\tau}}(q^2)$$

Short distance (in the $C_9^{SM} \sim 4.23$)

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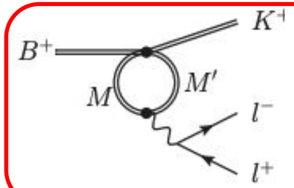
The structure of C_9

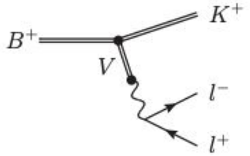
Cornella et al., Eur.Phys.J.C 80 (2020) 12, 1095



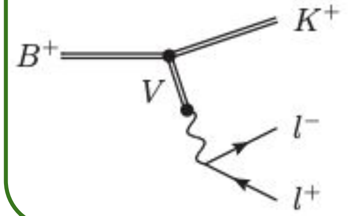
$$\Delta Y_{c\bar{c}}^{2\mathrm{P}}(q^2) = \sum_j \eta_j e^{i\delta_j} A_j^{2\mathrm{P}}(q^2)\,, \qquad A_j^{2\mathrm{P}}(q^2) = \frac{q^2}{\pi}\int_{s_0^j}^{\infty} \frac{ds}{s}\frac{\hat{\rho}_j(s)}{(s-q^2)}$$

$$\hat{\rho}_{DD}(s) = \left(1-\frac{4m_D^2}{s}\right)^{3/2}, \quad \hat{\rho}_{D^*D^*}(s) = \left(1-\frac{4m_{D^*}^2}{s}\right)^{3/2}, \quad \hat{\rho}_{DD^*}(s) = \left(1-\frac{4m_{\bar{D}}^2}{s}\right)^{1/2}$$

$$Y_{\mathrm{light}}^{1\mathrm{P}}(q^2) = \sum_{j=\rho,\omega,\phi} \eta_j\, e^{i\delta_j} A_j^{\mathrm{res}}(q^2)$$



$$\mathcal{C}_9^{\mu,\mathrm{eff}}(q^2) = \mathcal{C}_9^{\mu} + Y_{c\bar{c}}^{(0)} + \Delta Y_{c\bar{c}}^{1\mathrm{P}}(q^2) + \Delta Y_{c\bar{c}}^{2\mathrm{P}}(q^2) + Y_{\mathrm{light}}^{1\mathrm{P}}(q^2) + Y_{\tau\bar{\tau}}(q^2)$$



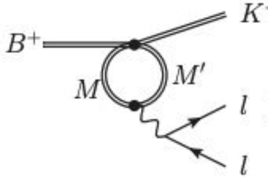
$$\Delta Y_{c\bar{c}}^{1\mathrm{P}}(q^2) = \sum_{j=\Psi(1S),\ldots,\Psi(4415)} \eta_j\, e^{i\delta_j} \frac{q^2}{m_j^2} A_j^{\mathrm{res}}(q^2)\,, \qquad A_j^{\mathrm{res}}(s) = \frac{m_j\Gamma_j}{(m_j^2 - s) - i m_j \Gamma_j}$$

Measuring the charm loop in Experiment

University of Zurich

The structure of C_9

Cornella et al., Eur.Phys.J.C 80 (2020) 12, 1095



$$Y_{\tau\bar{\tau}}(q^2) = -\frac{\alpha_{\rm em}}{2\pi} \mathcal{C}_9^\tau \left[h_S(m_\tau, q^2) - \frac{1}{3} h_P(m_\tau, q^2) \right]$$

$$\mathcal{C}_9^{\mu,\rm eff}(q^2) = \mathcal{C}_9^\mu + Y_{c\bar{c}}^{(0)} + \Delta Y_{c\bar{c}}^{1\rm P}(q^2) + \Delta Y_{c\bar{c}}^{2\rm P}(q^2) + Y_{\rm light}^{1\rm P}(q^2) + Y_{\tau\bar{\tau}}(q^2)$$

Crivellin et al., Phys.Rev.Lett. 122 (2019) 1, 011805:
Connection between RD/RD* and b→sμμ

Alguero et al., Phys.Rev.D 99 (2019) 7, 075017
Lepton Universal NP contribution to C_9

Cornella et al., Eur.Phys.J.C 80 (2020) 12, 1095:
Dependence on q^2

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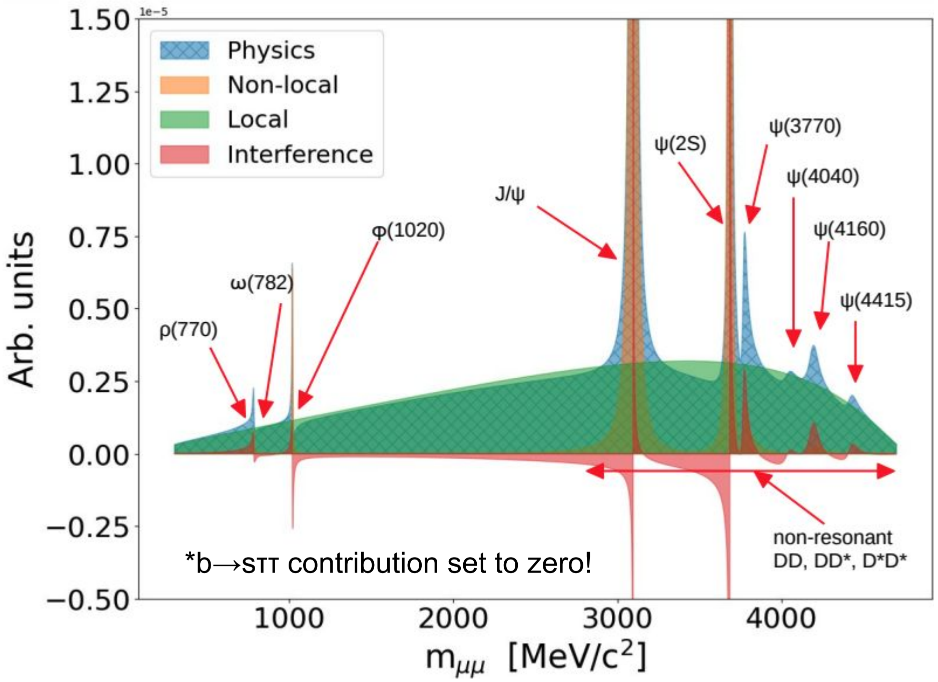
$B^+ \to K^+\mu\mu$

Courtesy of Lakshan Ram Madhan Mohan



Measuring the charm loop in Experiment

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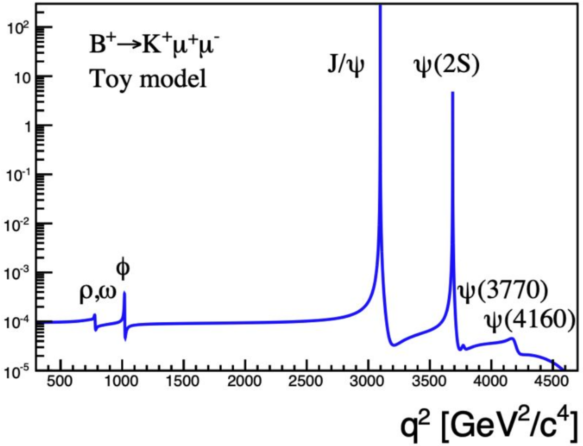
$B^+ \to K^+\mu\mu$

LHCb Coll., Eur.Phys.J.C 77 (2017) 3, 161

Courtesy of Patrick Owen

Decay	% of $B^+ \to K^+\mu^+\mu^-$
Penguin	0.6 %
$B^+ \to \rho K^+$	0.0003 %
$B^+ \to \omega K^+$	0.0006 %
$B^+ \to \phi K^+$	0.003 %
$B^+ \to J/\psi K^+$	92 %
$B^+ \to \psi(2S) K^+$	7.3 %
$B^+ \to \psi(3770) K^+$	0.007 %
$B^+ \to \psi(4040) K^+$	~ 0 %
$B^+ \to \psi(4160) K^+$	0.005 %
$B^+ \to \psi(4415) K^+$	~ 0 %



$$C_9^{\mu,\text{eff}}(q^2) = C_9^{\mu} + \Delta Y_{c\bar{c}}^{1\text{P}}(q^2) + Y_{\text{light}}^{1\text{P}}(q^2)$$

$$C_9^{\text{eff}} = C_9 + \sum_j \eta_j e^{i\delta_j} A_j^{\text{res}}(q^2)$$

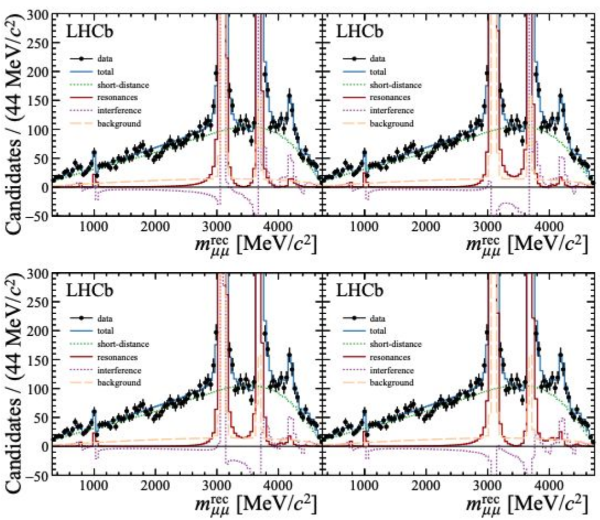
$$A_j^{\text{res}}(q^2) = \frac{m_{0\,j}\Gamma_{0\,j}}{(m_{0\,j}^2 - q^2) - i m_{0\,j}\Gamma_j(q^2)}$$

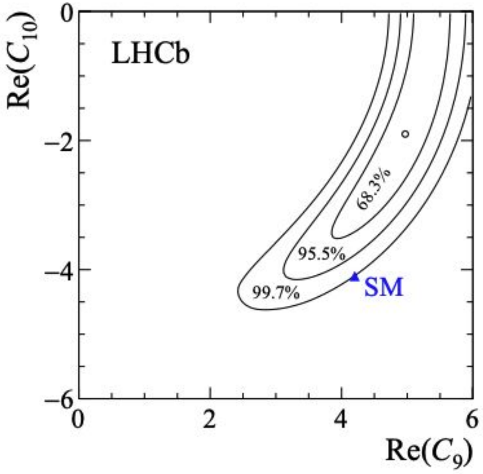
- Resonances added as relativistic BW
- Branching ratios of $B^+ \to VK^+$ constrained from the PDG (assuming factorization)
- Form-factors constrained from lattice QCD (Bailey et al., *Phys.Rev.D* 93 (2016) 2, 025026)
- Contribution of $D^{(*)}D^{(*)}$ ignored

Measuring the charm loop in Experiment

$B^+ \rightarrow K^+\mu\mu$

LHCb Coll., Eur.Phys.J.C 77 (2017) 3, 161





- Results show minimal interference between rare mode and J/Ψ and Ψ(2S)
- Allow to fit for C_9 and C_{10} leading to tension with respect to prediction (model dependent)
- Improved uncertainty of the form-factors
- Extension to B→K*μμ discussed in Egede et al., Eur.Phys.J.C 78 (2018) 6, 453

Measuring the charm loop in Experiment

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Extension to $B \to K^* \mu\mu$

$$\mathcal{A}_\lambda^{L,R} = N_\lambda \left\{ (C_9 \mp C_{10}) \mathcal{F}_\lambda(q^2) + \frac{2 m_b M_B}{q^2} \left[C_7 \mathcal{F}_\lambda^T(q^2) - 16\pi^2 \frac{M_B}{m_b} \mathcal{H}_\lambda(q^2) \right] \right\}$$

- Wilson coefficients
- Form factors
- Non-local hadronic matrix elements

Interesting theory development
Van Dyk et al., IPPP workshop 'Beyond the flavour anomalies'

- Combining the approaches of Egede et al., Eur.Phys.J.C 78 (2018) 6, 453 and Cornella et al., Eur.Phys.J.C 80 (2020) 12, 1095 to include all known contributions to C_9

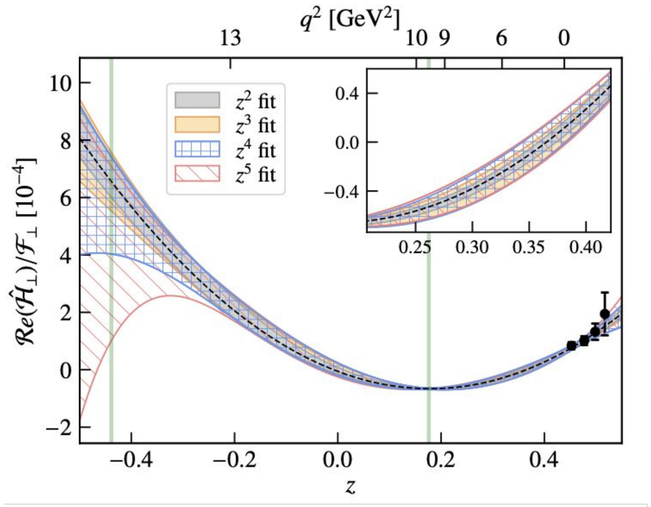
- Approach of Chrzaszcz et al., JHEP 10 (2019) 236 and Bobeth et al., Eur.Phys.J.C 78 (2018) 6, 451 consists of expanding $H(q^2)$ as polynomial in $z(q^2)$ fitting simultaneously with pseudo-observables coming from J/Ψ and Ψ(2S) and theory points at negative q^2

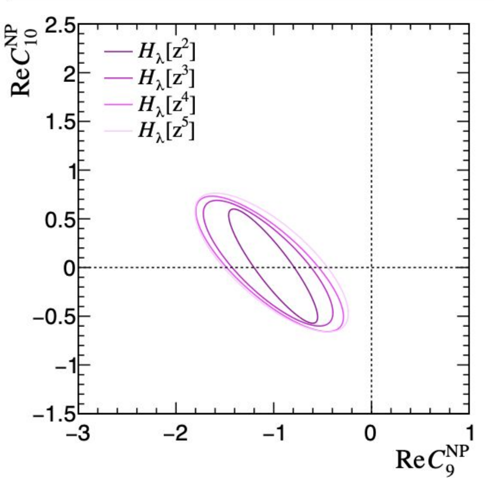
- Both approaches have their own merits and both are pursued at LHCb

Measuring the charm loop in Experiment

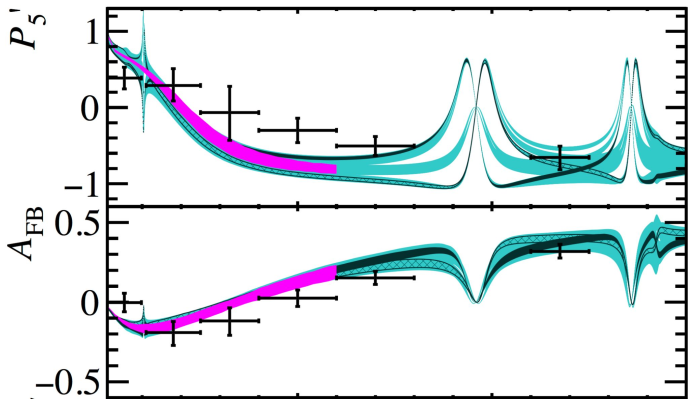
Extension to $B \to K^*\mu\mu$

[Chrzaszcz et al., JHEP 10 (2019) 236](#)





[Egede et al., Eur.Phys.J.C 78 (2018) 6, 453](#)

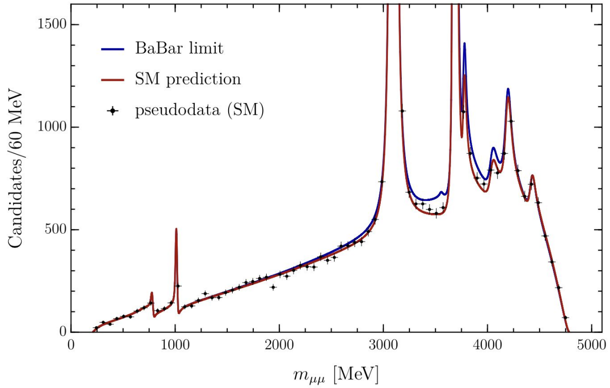


- Sensitivity studies with pseudo-experiment
- To be understood the tradeoff between model dependence and uncertainty

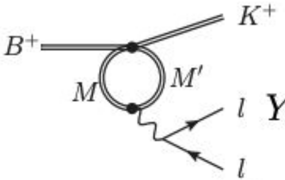
Other measurements

Hunting b→sττ in the dimuon spectrum of b→sμμ

Cornella et al., Eur.Phys.J.C 80 (2020) 12, 1095



$$\mathcal{B}(B^+ \to K^+\tau^+\tau^-) \approx \begin{cases} 8.7 \times 10^{-9} \times |\mathcal{C}_9^\tau|^2 & \mathcal{C}_9^\tau = \mathcal{C}_{10}^\tau \\ 2.7 \times 10^{-9} \times |\mathcal{C}_9^\tau|^2 & \mathcal{C}_{10}^\tau = 0\,. \end{cases}$$



$$Y_{\tau\bar{\tau}}(q^2) = -\frac{\alpha_{em}}{2\pi}\mathcal{C}_9^\tau \left[h_S(m_\tau, q^2) - \frac{1}{3}h_P(m_\tau, q^2)\right]$$

$$h_P\left(m, q^2\right) = \frac{2}{3} + \left(1 - \frac{4m^2}{q^2}\right) h_S\left(m, q^2\right), \qquad h_S\left(m, q^2\right) = 2 - G\left(1 - \frac{4m^2}{q^2}\right)$$

$$G(y) = \sqrt{|y|}\left\{\Theta(y)\left[\ln\left(\frac{1+\sqrt{y}}{1-\sqrt{y}}\right) - i\pi\right] + 2\,\Theta(-y)\arctan\left(\frac{1}{\sqrt{-y}}\right)\right\}$$

- Constraint on C_9^τ competitive with direct searches
- Allows to explore possible correlations between b→sμμ and b→cτν anomalies (Crivellin et al., Phys.Rev.Lett. 122 (2019) 1, 011805, Alguero et al., Phys.Rev.D 99 (2019) 7, 075017)

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Measurements of b→sττ

- Important to search b→sττ directly and indirectly
- Possible correlations with b→cτν
- Important to understand charm-loop

$$Br(B_s \to \tau\tau) < 6.8 \cdot 10^{-3} \ @95\%CL$$
$$Br(B^0 \to \tau\tau) < 2.1 \cdot 10^{-3} \ @95\%CL$$
$$Br(B^+ \to K^+\tau\tau) < 2.25 \cdot 10^{-3} \ @90\%CL$$
$$Br(B^0 \to K^*\tau\tau) < 2.0 \cdot 10^{-3} \ @90\%CL$$

LHCb Coll., Phys. Rev. Lett. **118**, 251802

BaBar Coll., Phys.Rev.Lett. 118 (2017) 3, 031802

Belle Coll., 2110.03871 [hep-ex]

See talk by Niladri Sahoo (parallel session on Wednesday afternoon)

Belle II Physics Book

Observables	Belle 0.71 ab^{-1} (0.12 ab^{-1})	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\mathrm{Br}(B^+ \to K^+\tau^+\tau^-) \cdot 10^5$	< 32	< 6.5	< 2.0
$\mathrm{Br}(B^0 \to \tau^+\tau^-) \cdot 10^5$	< 140	< 30	< 9.6
$\mathrm{Br}(B^0_s \to \tau^+\tau^-) \cdot 10^4$	< 70	< 8.1	—
$\mathrm{Br}(B^+ \to K^+\tau^\pm e^\mp) \cdot 10^6$	—	—	< 2.1
$\mathrm{Br}(B^+ \to K^+\tau^\pm \mu^\mp) \cdot 10^6$	—	—	< 3.3
$\mathrm{Br}(B^0 \to \tau^\pm e^\mp) \cdot 10^6$	—	—	< 1.6
$\mathrm{Br}(B^0 \to \tau^\pm \mu^\mp) \cdot 10^6$	—	—	< 1.3

BelleII Physics for Snowmass 2021

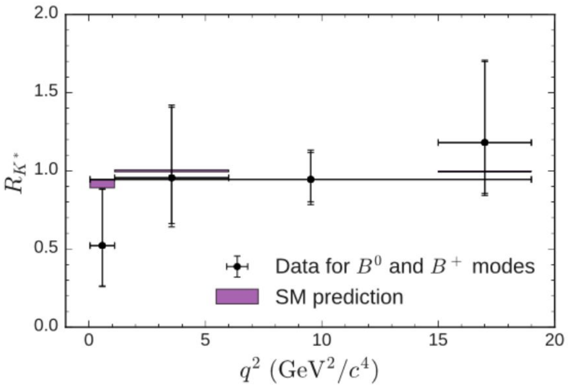
	$\mathcal{B}(B^0 \to K^{*0}\tau\tau)$ (had tag)	
ab^{-1}	"Baseline" scenario	"Improved" scenario
1	$< 3.2 \times 10^{-3}$	$< 1.2 \times 10^{-3}$
5	$< 2.0 \times 10^{-3}$	$< 6.8 \times 10^{-4}$
10	$< 1.8 \times 10^{-3}$	$< 6.5 \times 10^{-4}$
50	$< 1.6 \times 10^{-3}$	$< 5.3 \times 10^{-4}$

Belle II

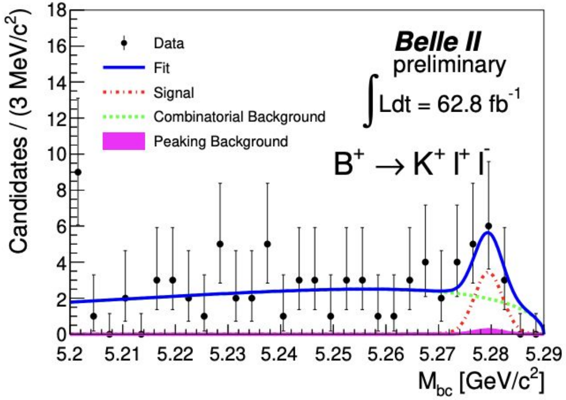
Future Prospects

Anomalies @ Belle II

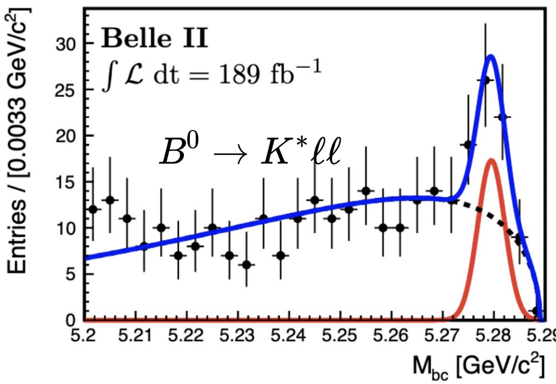
Belle Coll., Phys.Rev.Lett. 126 (2021) 16, 161801



Belle2-NOTE-PL-2021-005



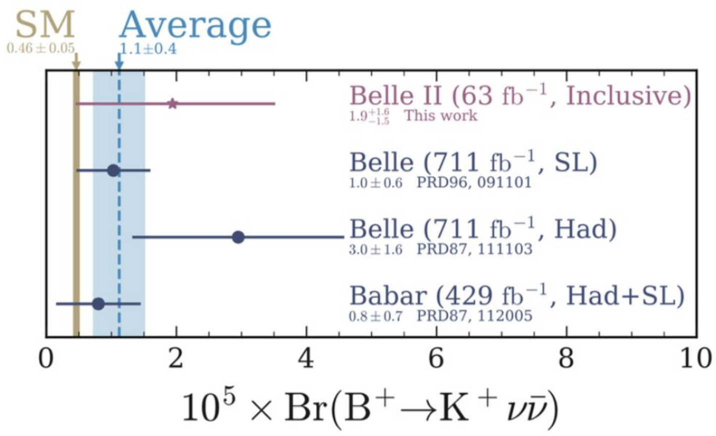
E Manoni Moriond EW 2022



- Belle II results will coming (already preliminary results with 63fb^{-1} and 190fb^{-1})
- Belle II expected uncertainty on LFU R-ratio about 2% with 50/ab (Belle II Physics Book)
- Already with few ab^{-1} Belle II will provide independent cross-check on the anomalies
- Belle II almost symmetric electron/muon reconstruction performances
- Belle II could provide absolute BR measurements for electrons and muons

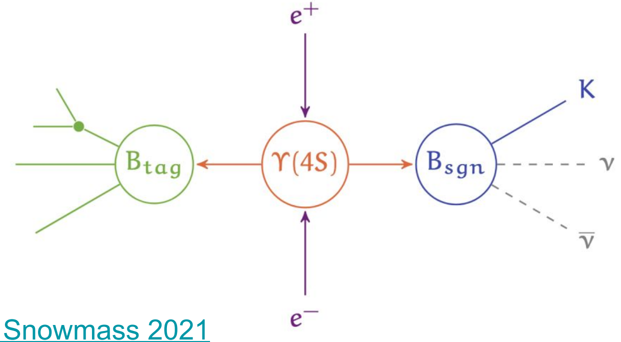
Future Prospects

Anomalies @ Belle II



$\mathcal{B}(B^+ \to K^+\nu\bar{\nu}) < 4.1 \times 10^{-5}$ @90% CL

Belle II Coll., Phys. Rev. Lett. **127**, 181802



BelleII Physics for Snowmass 2021

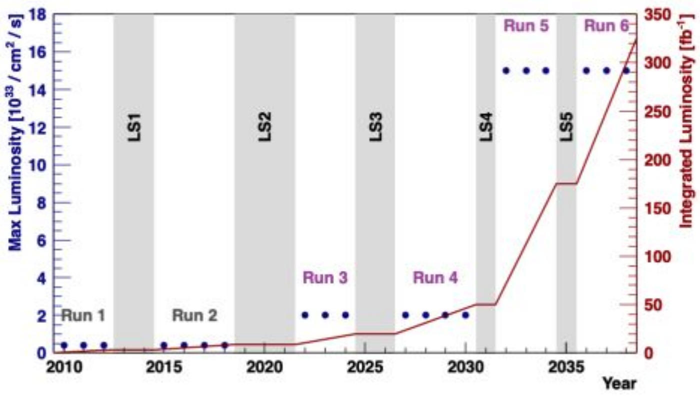
Decay	$1\,ab^{-1}$	$5\,ab^{-1}$	$10\,ab^{-1}$	$50\,ab^{-1}$
$B^+ \to K^+\nu\bar{\nu}$	0.55 (0.37)	0.28 (0.19)	0.21 (0.14)	0.11 (0.08)
$B^0 \to K^0_S\nu\bar{\nu}$	2.06 (1.37)	1.31 (0.87)	1.05 (0.70)	0.59 (0.40)
$B^+ \to K^{*+}\nu\bar{\nu}$	2.04 (1.45)	1.06 (0.75)	0.83 (0.59)	0.53 (0.38)
$B^0 \to K^{*0}\nu\bar{\nu}$	1.08 (0.72)	0.60 (0.40)	0.49 (0.33)	0.34 (0.23)

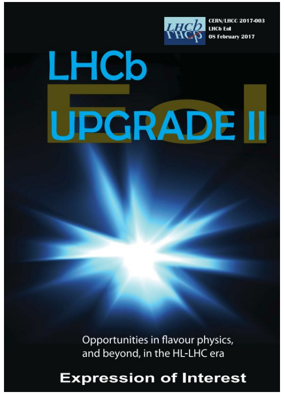
- B→Kνν includes all neutrino species
- Complementary probe to b→sττ → Possible correlation with semileptonic anomaly

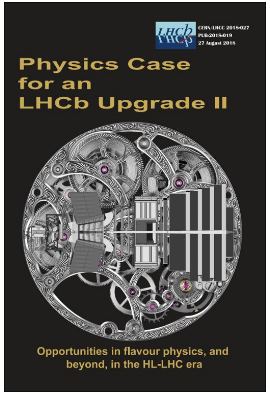
Future Prospects

LHCb Upgrades

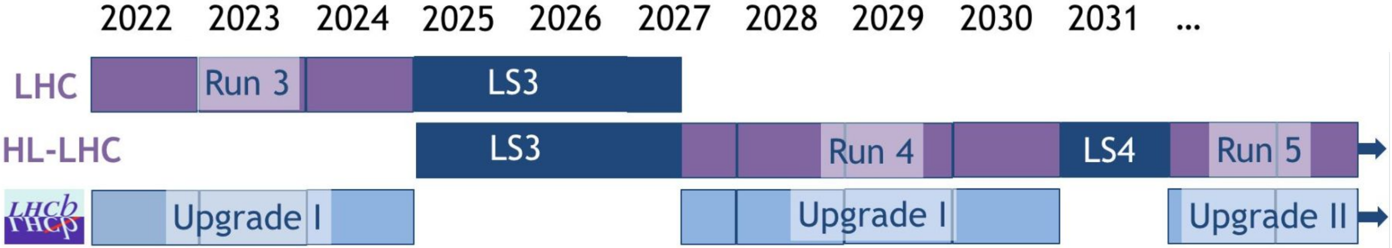
- LHCb Upgrade starts this year, almost an independent experiment







EoI LHCb Upgrade II | arXiv:1808.08865 | Framework TDR



Future Prospects

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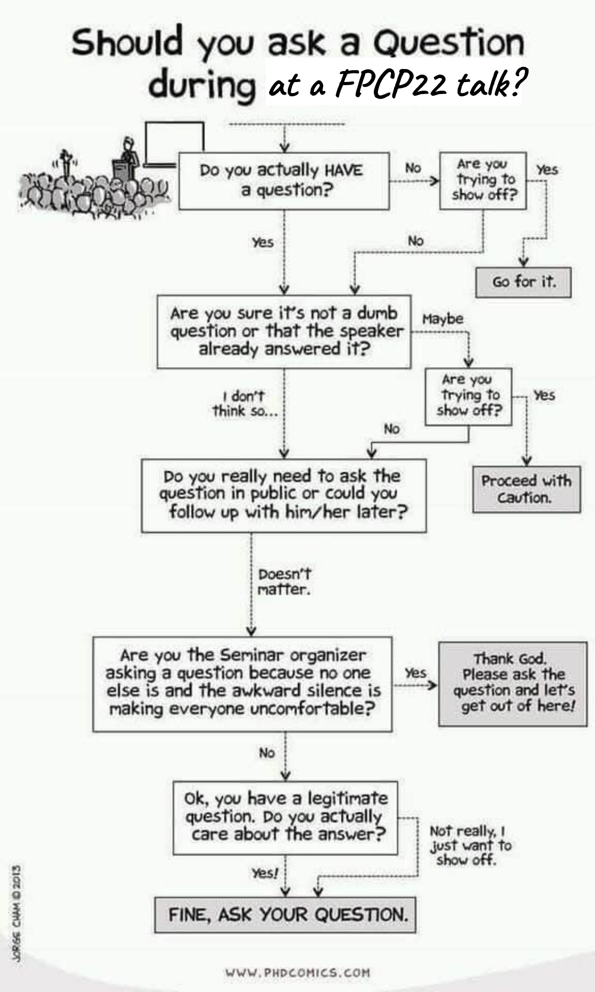
Conclusions

- Interesting anomalies in rare decays
- $b \to s\mu\mu$ anomaly limited by theory uncertainty (charm loop)
- Several ideas to improve our understanding of long distance hadronic contribution → Needed cooperation between experimentalists and theorists
- Intriguing discrepancies in LFU observables (experimentally challenging) → more measurements needed
- LHCb Upgrades and Belle II will clarify these anomalies

Thanks for the attention



Backup slides

i	I_i	f_i
$1s$	$\frac{3}{4}\left[\lvert\mathcal{A}_\parallel^{\rm L}\rvert^2+\lvert\mathcal{A}_\perp^{\rm L}\rvert^2+\lvert\mathcal{A}_\parallel^{\rm R}\rvert^2+\lvert\mathcal{A}_\perp^{\rm R}\rvert^2\right]$	$\sin^2\theta_K$
$1c$	$\lvert\mathcal{A}_0^{\rm L}\rvert^2+\lvert\mathcal{A}_0^{\rm R}\rvert^2$	$\cos^2\theta_K$
$2s$	$\frac{1}{4}\left[\lvert\mathcal{A}_\parallel^{\rm L}\rvert^2+\lvert\mathcal{A}_\perp^{\rm L}\rvert^2+\lvert\mathcal{A}_\parallel^{\rm R}\rvert^2+\lvert\mathcal{A}_\perp^{\rm R}\rvert^2\right]$	$\sin^2\theta_K\cos 2\theta_l$
$2c$	$-\lvert\mathcal{A}_0^{\rm L}\rvert^2-\lvert\mathcal{A}_0^{\rm R}\rvert^2$	$\cos^2\theta_K\cos 2\theta_l$
3	$\frac{1}{2}\left[\lvert\mathcal{A}_\perp^{\rm L}\rvert^2-\lvert\mathcal{A}_\parallel^{\rm L}\rvert^2+\lvert\mathcal{A}_\perp^{\rm R}\rvert^2-\lvert\mathcal{A}_\parallel^{\rm R}\rvert^2\right]$	$\sin^2\theta_K\sin^2\theta_l\cos 2\phi$
4	$\sqrt{\frac{1}{2}}{\rm Re}(\mathcal{A}_0^{\rm L}\mathcal{A}_\parallel^{\rm L*}+\mathcal{A}_0^{\rm R}\mathcal{A}_\parallel^{\rm R*})$	$\sin 2\theta_K\sin 2\theta_l\cos\phi$
5	$\sqrt{2}{\rm Re}(\mathcal{A}_0^{\rm L}\mathcal{A}_\perp^{\rm L*}-\mathcal{A}_0^{\rm R}\mathcal{A}_\perp^{\rm R*})$	$\sin 2\theta_K\sin\theta_l\cos\phi$
$6s$	$2{\rm Re}(\mathcal{A}_\parallel^{\rm L}\mathcal{A}_\perp^{\rm L*}-\mathcal{A}_\parallel^{\rm R}\mathcal{A}_\perp^{\rm R*})$	$\sin^2\theta_K\cos\theta_l$
7	$\sqrt{2}{\rm Im}(\mathcal{A}_0^{\rm L}\mathcal{A}_\parallel^{\rm L*}-\mathcal{A}_0^{\rm R}\mathcal{A}_\parallel^{\rm R*})$	$\sin 2\theta_K\sin\theta_l\sin\phi$
8	$\sqrt{\frac{1}{2}}{\rm Im}(\mathcal{A}_0^{\rm L}\mathcal{A}_\perp^{\rm L*}+\mathcal{A}_0^{\rm R}\mathcal{A}_\perp^{\rm R*})$	$\sin 2\theta_K\sin 2\theta_l\sin\phi$
9	${\rm Im}(\mathcal{A}_\parallel^{\rm L*}\mathcal{A}_\perp^{\rm L}+\mathcal{A}_\parallel^{\rm R*}\mathcal{A}_\perp^{\rm R})$	$\sin^2\theta_K\sin^2\theta_l\sin 2\phi$

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Backup slides

- The decay is described by six complex amplitudes $A^{L,R}_{0,\|,\perp}$
- Correspond to different transversity state of the K^*
- and different (left- and right-handed) chiralities of the dimuon system

$$
\begin{aligned}
F_L &= \frac{A_0^2}{A_\|^2 + A_\perp^2 + A_0^2} = 1 - F_T \\
S_3 &= \frac{1}{2}\frac{A_\perp^{L2} - A_\|^{L2}}{A_\|^2 + A_\perp^2 + A_0^2} + L \to R \\
S_4 &= \frac{1}{\sqrt{2}}\frac{\Re(A_0^{L*}A_\|^L)}{A_\|^2 + A_\perp^2 + A_0^2} + L \to R \\
S_5 &= \sqrt{2}\frac{\Re(A_0^{L*}A_\perp^L)}{A_\|^2 + A_\perp^2 + A_0^2} - L \to R \\
A_{FB} &= \frac{8}{3}\frac{\Re(A_\perp^{L*}A_\|^L)}{A_\|^2 + A_\perp^2 + A_0^2} - L \to R \\
S_7 &= \sqrt{2}\frac{\Im(A_0^{L*}A_\|^L)}{A_\|^2 + A_\perp^2 + A_0^2} + L \to R \\
S_8 &= \frac{1}{\sqrt{2}}\frac{\Im(A_0^{L*}A_\perp^L)}{A_\|^2 + A_\perp^2 + A_0^2} + L \to R \\
S_9 &= \frac{\Im(A_\perp^{L*}A_\|^L)}{A_\|^2 + A_\perp^2 + A_0^2} - L \to R
\end{aligned}
$$

- $\Gamma = |A_\||^2 + |A_0|^2 + |A_\perp|^2$
- Let's see how the amplitudes depend on Wilson coefficients and form factors

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Backup slides

$$A_{\perp}^{L,R} \propto [(C_9^{eff} + C_9^{eff\prime}) \mp (C_{10}^{eff} + C_{10}^{eff\prime}) \frac{V(q^2)}{m_B + m_{K^*}} + \frac{2m_b}{q^2}(C_7^{eff} + C_7^{eff\prime}) T_1(q^2)]$$

$$A_{||}^{L,R} \propto [(C_9^{eff} - C_9^{eff\prime}) \mp (C_{10}^{eff} - C_{10}^{eff\prime}) \frac{A_1(q^2)}{m_B + m_{K^*}} + \frac{2m_b}{q^2}(C_7^{eff} - C_7^{eff\prime}) T_2(q^2)]$$

$$A_0^{L,R} \propto [(C_9^{eff} - C_9^{eff\prime}) \mp (C_{10}^{eff} - C_{10}^{eff\prime})] \times [(m_B^2 - m_{K^*}^2 - q^2)(m_B + m_{K^*} A_1(q^2) - \lambda \frac{A_2(q^2)}{m_B + m_{K^*}})] + 2m_b(C_7^{eff} + C_7^{eff\prime})[(m_B^2 + 3m_{K^*}^2 - q^2) T_2(q^2) - \frac{\lambda}{m_B^2 - m_{K^*}^2 T_3(q^2)}]$$

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Backup slides

$$R_1 = \frac{T_1}{V} \sim 1$$
$$R_2 = \frac{T_2}{A_1} \sim 1$$
$$R_3 = \frac{T_{23}}{A_{12}} \sim \frac{q^2}{m_B^2}$$

$$A_\perp^{L,R} = \sqrt{2} N m_B (1-\hat{s}) \left[(\mathcal{C}_9^{\text{eff}} + \mathcal{C}_9^{\text{eff}\prime}) \mp (\mathcal{C}_{10} + \mathcal{C}_{10}^\prime) + \frac{2\hat{m}_b}{\hat{s}} (\mathcal{C}_7^{\text{eff}} + \mathcal{C}_7^{\text{eff}\prime}) \right] \xi_\perp (E_{K^*})$$

$$A_\parallel^{L,R} = -\sqrt{2} N m_B (1-\hat{s}) \left[(\mathcal{C}_9^{\text{eff}} - \mathcal{C}_9^{\text{eff}\prime}) \mp (\mathcal{C}_{10} - \mathcal{C}_{10}^\prime) + \frac{2\hat{m}_b}{\hat{s}} (\mathcal{C}_7^{\text{eff}} - \mathcal{C}_7^{\text{eff}\prime}) \right] \xi_\perp (E_{K^*})$$

$$A_0^{L,R} = -\frac{N m_B (1-\hat{s})^2}{2\hat{m}_{K^*}\sqrt{\hat{s}}} \left[(\mathcal{C}_9^{\text{eff}} - \mathcal{C}_9^{\text{eff}\prime}) \mp (\mathcal{C}_{10} - \mathcal{C}_{10}^\prime) + 2\hat{m}_b (\mathcal{C}_7^{\text{eff}} - \mathcal{C}_7^{\text{eff}\prime}) \right] \xi_\parallel (E_{K^*})$$

P-basis (P_1,...,P_8) FF appears in the numerator and in the denominator

$$P_5^\prime \propto \frac{\mathcal{R}(A_0 A_\perp)}{\sqrt{|A_0|^2 \times |A_\perp|^2}}$$

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Backup slides

$$P_1 = A_T^{(2)} = \frac{2S_3}{(1-F_L)} = \frac{A_\perp^{L2} - A_\parallel^{L2}}{A_\parallel^2 + A_\perp^2} + L \to R$$

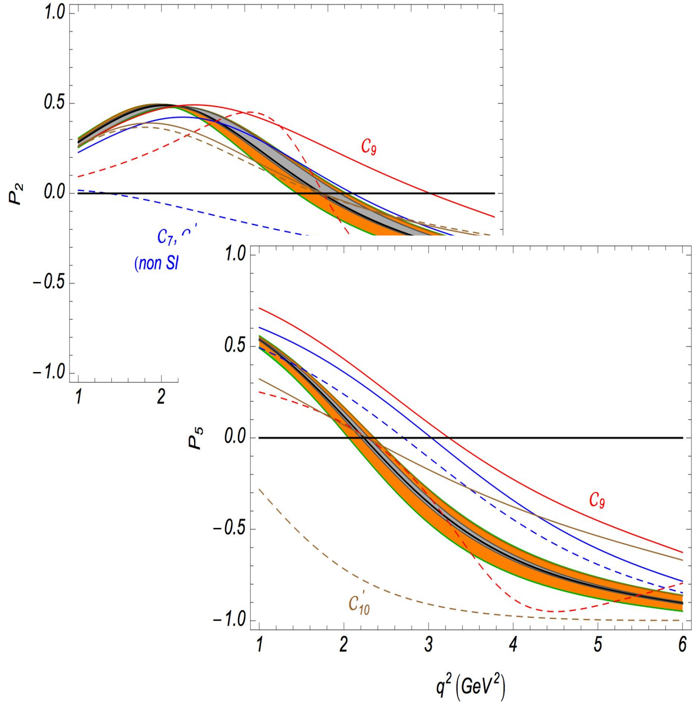
$$P_2 = 2A_T^{Re} = \frac{2A_{FB}}{3(1-F_L)} \propto \frac{\Re(A_\perp^{L*}A_\parallel^L)}{A_\parallel^2 + A_\perp^2} - L \to R$$

$$P_3 = \frac{S_9}{(1-F_L)} = \frac{\Im(A_\perp^{L*}A_\parallel^L)}{A_\parallel^2 + A_\perp^2} - L \to R$$

$$P_4' = \frac{S_4}{\sqrt{F_L(1-F_L)}} \propto \frac{\Re(A_0^{L*}A_\parallel^L)}{\sqrt{|A_0|^2|A_\parallel|^2}} + L \to R$$

$$P_5' = \frac{S_5}{\sqrt{F_L(1-F_L)}} \propto \frac{\Re(A_0^{L*}A_\perp^L)}{\sqrt{|A_\perp|^2|A_0|^2}} - L \to R$$

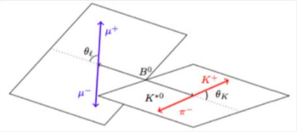
$$P_6' = \frac{S_7}{\sqrt{F_L(1-F_L)}} \propto \frac{\Im(A_0^{L*}A_\parallel^L)}{\sqrt{|A_\parallel|^2|A_0|^2}} + L \to R$$



Backup slides

A.Mauri ICHEP2018

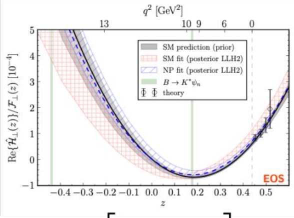
* Extended unbinned amplitude fit: $\frac{1}{\Gamma}\frac{d^4\Gamma}{dq^2\,d\Omega}$



* Parametrization introduced by Bobeth et al. [arxiv:1707.07305]

$$\mathcal{A}_\lambda^{L,R} = N_\lambda \left\{ (C_9 \mp C_{10})\mathcal{F}_\lambda(q^2) + \frac{2m_b M_B}{q^2}\left[C_7 \mathcal{F}_\lambda^T(q^2) - 16\pi^2 \frac{M_B}{m_b}\mathcal{H}_\lambda(q^2) \right] \right\}$$

- Wilson coefficients
- Form factors
- Non-local hadronic matrix elements ("charm loop")



mapping: $q^2 \to z(q^2)$

$$\mathcal{H}_\lambda(z) = \frac{1 - z z^*_{J/\psi}}{z - z_{J/\psi}} \frac{1 - z z^*_{\psi(2S)}}{z - z_{\psi(2S)}} \hat{\mathcal{H}}_\lambda(z)$$

extract the poles

polynomial expansion →

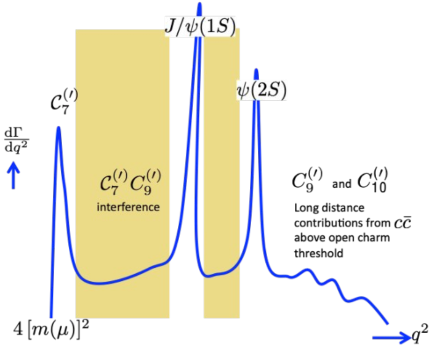
$$\hat{\mathcal{H}}_\lambda(z) = \left[\sum_k \alpha_k^{(\lambda)} z^k \right] \mathcal{F}_\lambda(z)$$

* analytic within $|z| = 1$
* truncation at order z^k
  → which order of z describes well nature is a-priori unknow

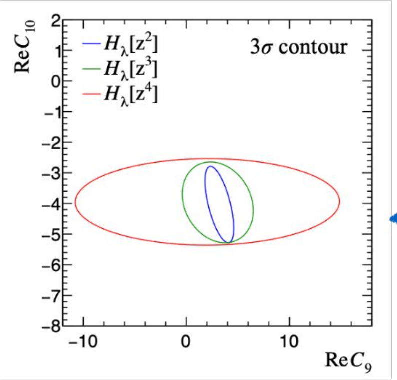
Backup slides

A.Mauri ICHEP2018

- signal yield fitted to $\mathcal{BR}$
- full set of parameters floating:
  - CKM, FF ⟶ multi-Gauss. constraints
  - H ⟶ free floating
- sensitivity based in signal-only toys
  - no experimental effects (*e.g.* background, s-wave, acceptance, efficiency)



[1.1, 9.0] & [10.0, 13.0] GeV2



Scanning the order of the z-expansion:

- C_9: Strong dependence on the cut-off ✗
- C_{10}: unaffected! ✓

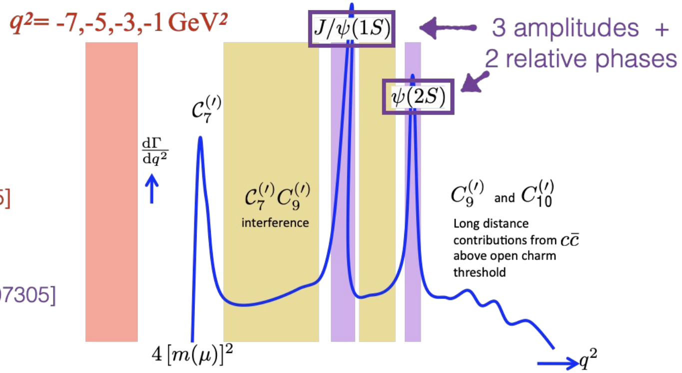
* Direct fits to with different approaches have been proposed in **JHEP 11 (2017) 176** and **EPJ C78 (2018) n.6 453**

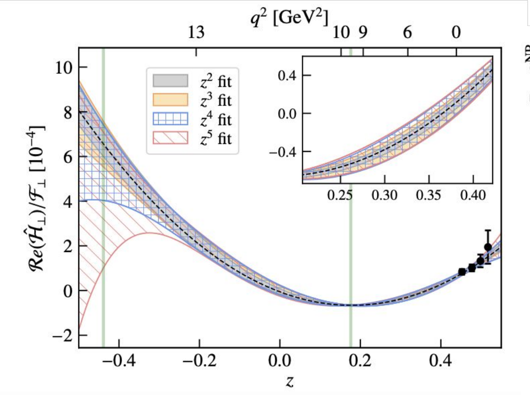
Backup slides

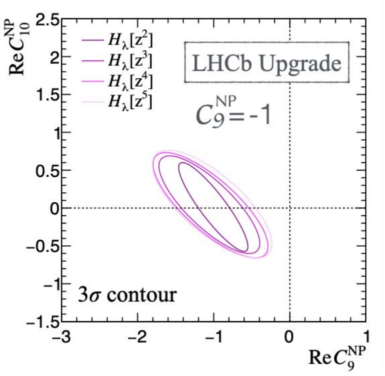
A.Mauri ICHEP2018

Combined fit to:

- semi-muonic $B \to K^*\mu\mu$ decays
- theory points at negative q^2
  - reliable theory predictions [arxiv:1707.07305]
- hadronic $B \to K^*\{J/\psi,\ \psi_{(2S)}\}$ decays
  - sets of 5 pseudo-observables [arxiv:1707.07305]







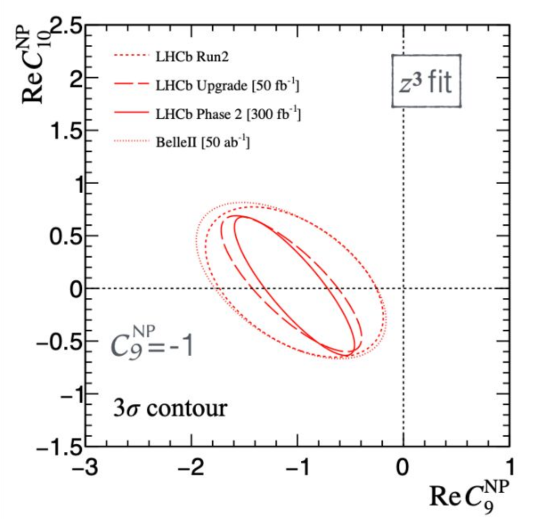
- Uncertainty only slightly increases after z^3 fits
- We can access in a quantitative way this model-dependency

Backup slides

A.Mauri ICHEP2018

- Measurement of C_{10} independent on the lack of knowledge on the charm-loop
- Precision saturates due to the form factors uncertainty after LHCb Run II
  - we have been very conservative doubling the FF uncertainty of JHEP 08, 098 (2016)
- Possible 3σ observation after LHCb Run II (depending on the NP scenario…)

Sensitivity for different statistical scenarios



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Backup slides

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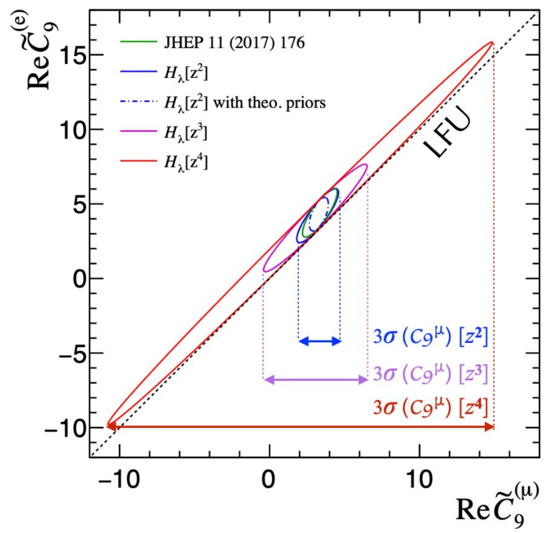
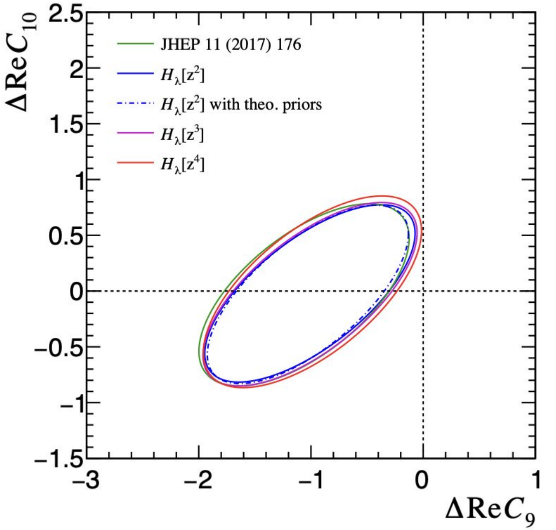
$C9_{\mu}^{NP} = C9_{\mu}^{SM}$ -1



- $C_9^{(\ell)}$ strongly model-dependent
- **Model-independent** determination of the **difference** between electron and muon **WCs**

$$\Delta C_i = C_i^{(\mu)} - C_i^{(e)}$$

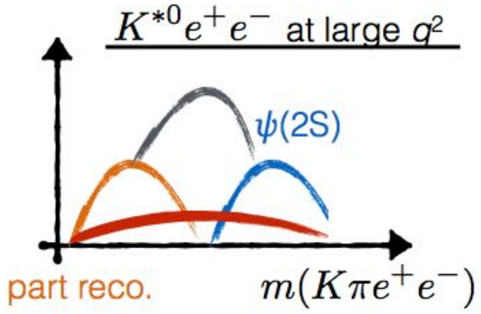
  - Insensitive to the parametrization of the charm loop
  - Significance wrt LFU hypothesis is unbiased

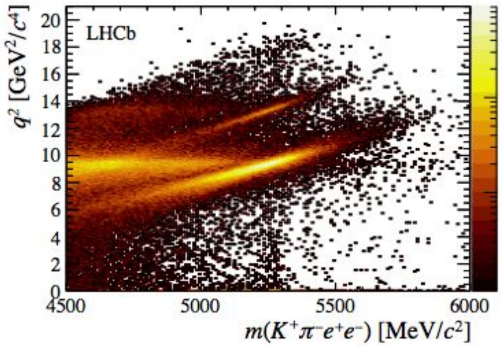


Determination of ΔC9 and ΔC10 is model-independent

Backup slides

- Very little rate for q^2<1.0 GeV^2 (no photon pole)
- Working to add high q^2 bin – difficulty same for R_K and $R_K{}^*$
  - Rare decays with higher K* resonances can leak into signal region from below
  - ψ(2S)K* decays can leak into signal region on the upper side
  - Signal sandwiched between these and hence difficult to fit reliably





Backup slides

- Non-exclusive R-ratios affected by larger theory uncertainty, but can still be rigorously combined
- Neglecting lepton masses ($q^2 >> m_l^2$) (very good approximation) no interference between left and right handed lepton currents

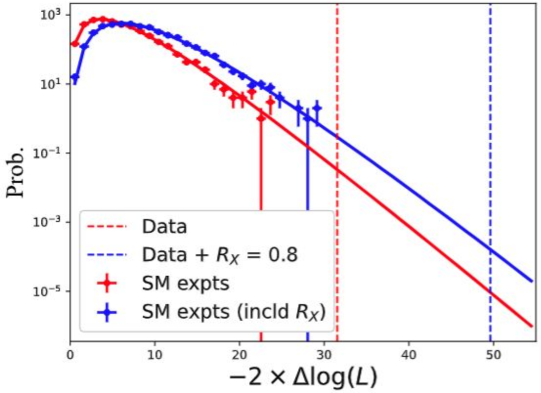
$$\mathcal{A}(B \to X_s \ell^+ \ell^-) \propto (\mathcal{M}^\ell_{X,L})^\alpha (J^\ell_L)_\alpha + (\mathcal{M}^\ell_{X,R})^\alpha (J^\ell_R)_\alpha$$

$$\left\langle X_s \middle| \sum_i C_i O_i \middle| B \right\rangle \qquad \bar{\ell}_L \gamma^\alpha \ell_L$$

After integrating on anything apart for q^2

$$\frac{d\Gamma^\ell_X}{dq^2} = \frac{d\Gamma^\ell_{X,L}}{dq^2} + \frac{d\Gamma^\ell_{X,R}}{dq^2} \qquad \frac{d\Gamma^\ell_{X,R}}{dq^2} = \frac{d\Gamma^\ell_{X,L}}{dq^2}\Bigg|_{\{C^\ell_L \to C^\ell_R,\ C'^\ell_L \to C'^\ell_R\}}$$

$$R_X = \frac{\left\{(C^\mu_L)^2 + (C'^\mu_L)^2 + \langle \eta^0_X \rangle C^\mu_L C'^\mu_L + C_7 \cdot \left(\langle \eta^{77}_X \rangle C_7 + \langle \eta^{79}_X \rangle C^\mu_L + \langle \eta'^{79}_X \rangle C'^\mu_L\right)\right\} + (L \to R)}{\left\{(C^e_L)^2 + (C'^e_L)^2 + \langle \eta^0_X \rangle C^e_L C'^e_L + C_7 \cdot \left(\langle \eta^{77}_X \rangle C_7 + \langle \eta^{79}_X \rangle C^e_L + \langle \eta'^{79}_X \rangle C'^e_L\right)\right\} + (L \to R)}$$



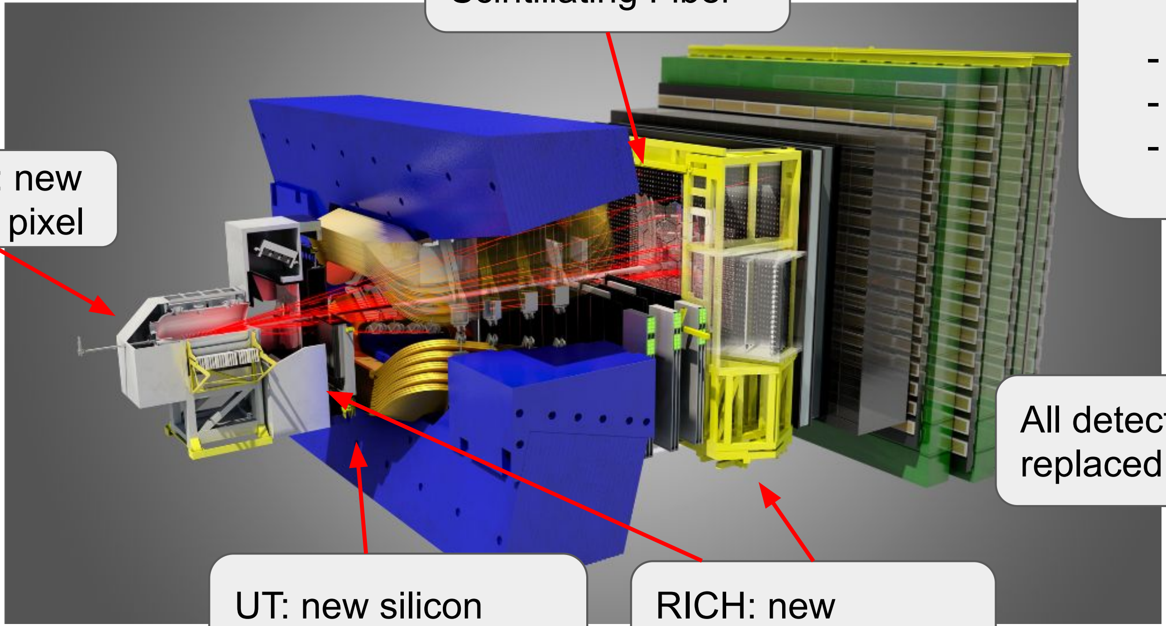
Backup slides

SciFi: new Scintillating Fiber

Brand New Detector (almost independent experiment):

- 40MHz redout
- Fully software trigger
- Instantaneous luminosity $2x10^{33}$ $cm^{-2}s^{-1}$

VELO: new silicon pixel

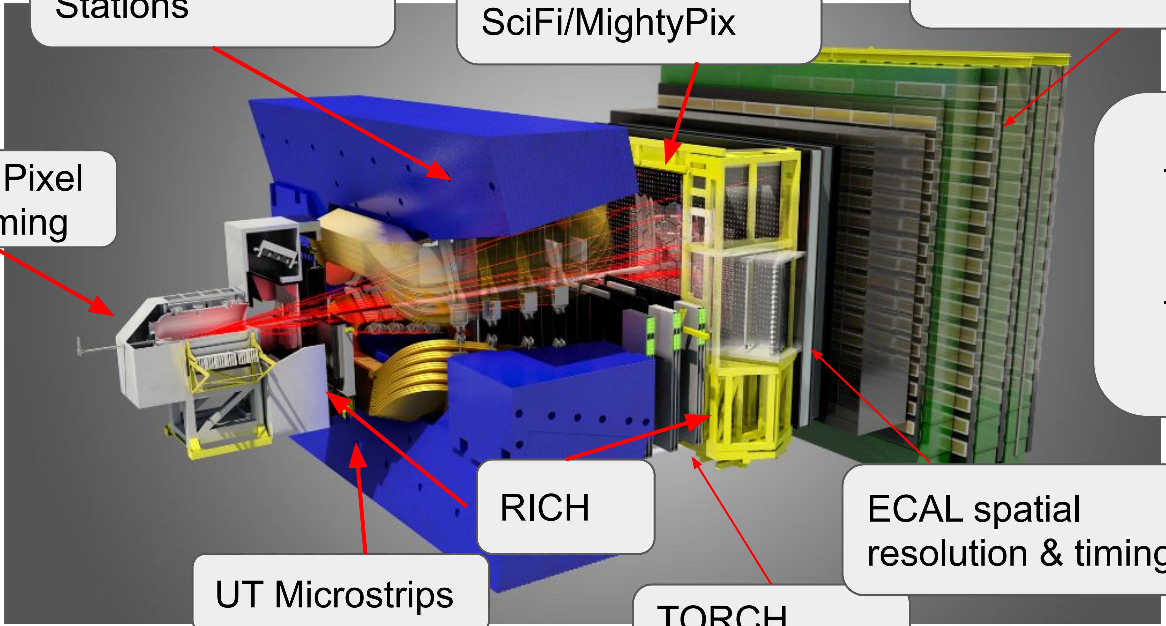


All detectors: replaced electronics

UT: new silicon strip detector

RICH: new photodetectors

Backup slides



- Plan running at instantaneous luminosity up to 10^{34} $cm^{-2}s^{-1}$
- Require excellent spatial resolution and timing