Towards the discovery of new physics with lepton-universality ratios of $b \to s\, l\, l$ decays

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Outline

- Background
- Purpose
- Theoretical framework
- Results and Discussions
- Summary and Outlook

$$\mathcal{L}_{SM} = \underbrace{\frac{1}{4}\mathbf{W}_{\mu\nu}\cdot\mathbf{W}^{\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}G^{a}_{\mu\nu}G^{\mu\nu}_{a}}_{\text{kinetic energies and self-interactions of the gauge bosons}}$$

$$+ \underbrace{\bar{L}\gamma^{\mu}(i\partial_{\mu} - \frac{1}{2}g\tau\cdot\mathbf{W}_{\mu} - \frac{1}{2}g'YB_{\mu})L + \bar{R}\gamma^{\mu}(i\partial_{\mu} - \frac{1}{2}g'YB_{\mu})R}_{\text{kinetic energies and electroweak interactions of fermions}}$$

$$+ \underbrace{\frac{1}{2}\left|(i\partial_{\mu} - \frac{1}{2}g\tau\cdot\mathbf{W}_{\mu} - \frac{1}{2}g'YB_{\mu})\,\phi\right|^{2} - V(\phi)}_{W^{\pm},Z,\gamma\text{ and Higgs masses and couplings}}$$

$$+ \underbrace{g''(\bar{q}\gamma^{\mu}T_{a}q)\,G^{a}_{\mu}}_{\text{interactions between quarks and gluons}} + \underbrace{(G_{1}\bar{L}\phi R + G_{2}\bar{L}\phi_{c}R + h.c.)}_{\text{fermion masses and couplings to Higgs}}$$

Lepton universality (LU) in SM:

The interactions between leptons and gauge bosons are the same for all leptons.

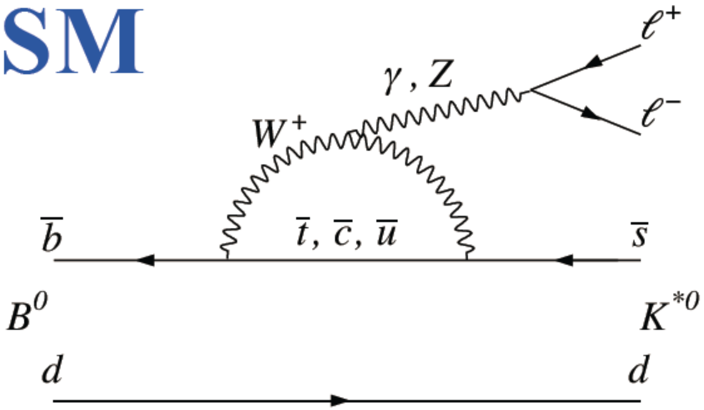
If LU is violated, LUV effect can be determined by R_{K^*} and R_K.

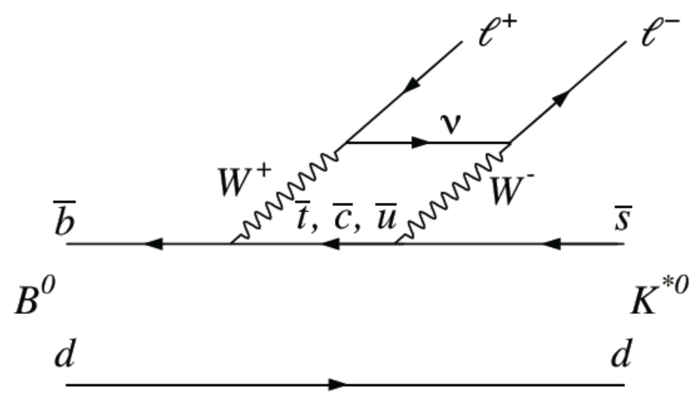
Lepton universality of $B -> K^{(*)} ll$ decays

$$R_{K^{(*)}}^{\rm SM} = \frac{\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B \to K^{(*)}e^+e^-)} \simeq 1$$ [1,2]

Very clean !

SM





[1] G. Hiller and F. Kruger, Phys. Rev. D69, 074020 (2004), hep-ph/0310219.

[2] M. Bordone, G. Isidori, and A. Pattori, Eur. Phys. J. C76, 440 (2016), 1605.07633.

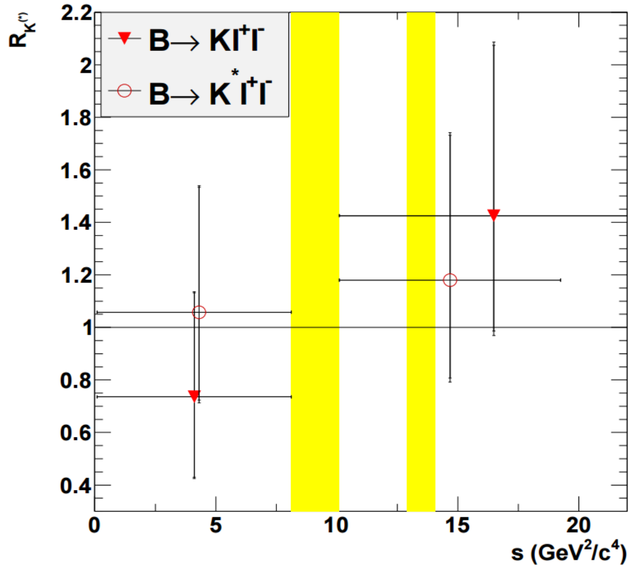
Experimental observations

The first measurements :

Belle(2009):

$$R_{K^*} = 0.83 \pm 0.17 \pm 0.08 \qquad R_K = 1.03 \pm 0.19 \pm 0.06$$ [3]

BaBar(2012):



[4]

However, because of large experimental uncertainties, there is no significant deviation from SM prediction.

[3] J. T. Wei et al. (Belle), Phys. Rev. Lett. 103, 171801 (2009), 0904.0770.

[4] J. P. Lees et al. (BaBar), Phys. Rev. D86, 032012 (2012), 1204.3933.

LHCb(2014):

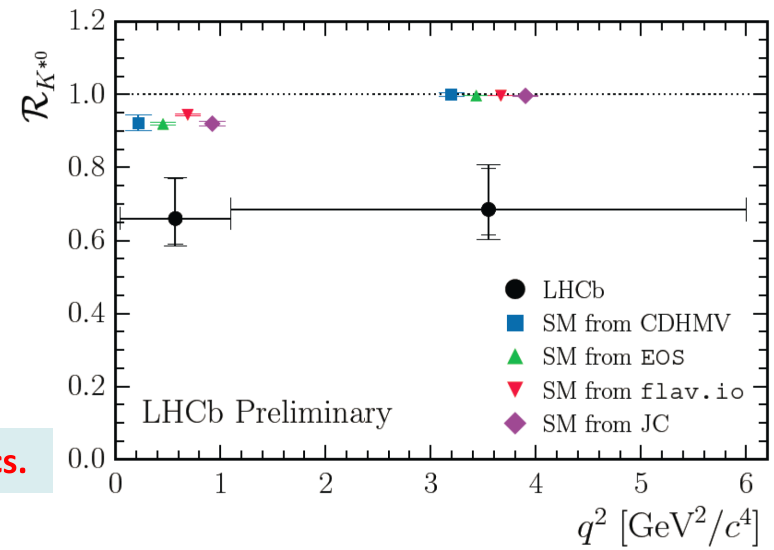
$$R_{K[1,6]} = \frac{\mathcal{B}(B \to K\mu^+\mu^-)}{\mathcal{B}(B \to Ke^+e^-)} = 0.745^{+0.090}_{-0.074}(\text{stat}) \pm 0.036(\text{syst})$$ [5]

- **Tension with SM ~2.6σ.**

LHCb(2017):

$$R_{K^*[0.045,1.1]\ \text{GeV}^2} = 0.660^{+0.110}_{-0.070} \pm 0.024$$

$$R_{K^*[1.1,6]\ \text{GeV}^2} = 0.685^{+0.113}_{-0.069} \pm 0.047$$



[6]

These anomalies may be caused by effects of new physics.

- **Tension with SM ~2.3σ and 2.4σ, respectively.**

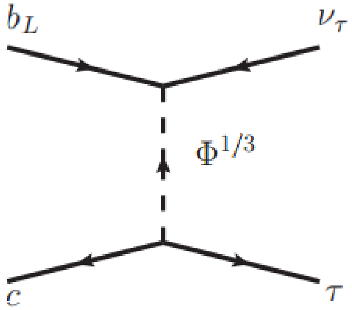
[5]R. Aaij et al. (LHCb), Phys. Rev. Lett. 113, 151601 (2014), 1406.6482.

[6]S. Bifani, in LHCb Seminar at CERN (April 18th 2017), URL https://indico.cern.ch/event/580620/.

Some interpretations for $R_{K^{(*)}}$ anomaly

NP is a good choice, and its effect can eliminate these anomalies.

Leptoquark model (invariant under the SM gauge group $SU(3)_c \times SU(2)_L \times U(1)_Y$):



(i PhysRevD.94.115021;

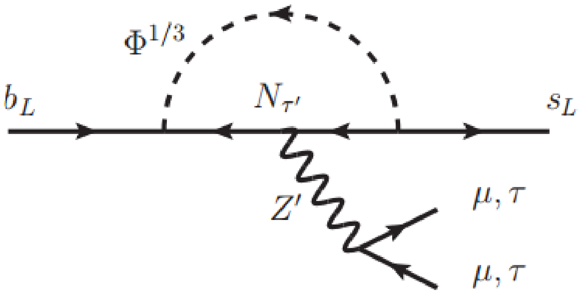
(ii PhysRevD.95.035027.

Z′ model (there is an additional U(1)′ gauge symmetry):

(i PhysRevD.97.115003;

(ii PhysRevD.96.075012;

(iii PhysRevD.96.115022.



Alternatively, an independent-model method to determine the effects of new physics is effective field theory (EFT).

Effective field theories: Bottom-up approach to new physics

Guiding principle

Construct $\mathcal{L}$ from most general local operators $\mathcal{O}_k$ made of $\phi \in u, d, s, c, b, l, \nu, F_{\mu\nu}, G_{\mu\nu}$, subject to Lorentz and $SU(3)_c \times U(1)_{em}$ invariance

$$\mathcal{H}_{\rm eff} = \mathcal{H}_{\rm eff}^{\rm had} + \mathcal{H}_{\rm eff}^{\rm sl},$$

$$\mathcal{H}_{\rm eff}^{\rm had} = \frac{4G_F}{\sqrt{2}} \sum_{p=u,c} \lambda_p \Big[C_1 Q_1^p + C_2 Q_2^p + \sum_{i=3\ldots6} C_i P_i + C_{8g} Q_{8g} \Big],$$

$$\mathcal{H}_{\rm eff}^{\rm sl} = -\frac{4G_F}{\sqrt{2}} \lambda_t \Big[C_7 Q_{7\gamma} + C_7' Q_{7\gamma}' + C_9 Q_{9V} + C_9' Q_{9V}' + C_{10} Q_{10A} + C_{10}' Q_{10A}' + C_S Q_S + C_S' Q_S' + C_P Q_P + C_P' Q_P' + C_T Q_T + C_T' Q_T' \Big].$$

- New physics manifest at the operator level through...
  - Different values of the Wilson coefficients $C_i^{\rm expt.} = C_i^{\rm SM} + \delta C_i$
  - The Wilson coefficients can be complex and introduce new sources of $C\!\!\!/P$

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Our approach and objective

➢ Objective：

Using theoretical observables for b->sll transition to fit the latest all experimental data, we can constrain the range of NP degree of freedom (Wilson coefficients) by a chi^2 fit. Further, we also can rule out some unreliable NP models according to d.o.f range.

➢ Approach：

(1) Statistic approach: Frequentist.

(2)Form factors: LCSR & Dyson-Schwinger + EFT correlations.

(3)Include the contribution of NLO charm loop.

(4)Conservatively estimate the error of input parameters.

(5)Include almost all experiment data at present.

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Low energy effective Hamiltonian approach to $b \to s\, l\, l$ decays

ΔB = 1 weak effective Hamiltonian [7] :

$$\mathcal{H}_{\rm eff} = \mathcal{H}_{\rm eff}^{\rm had} + \mathcal{H}_{\rm eff}^{\rm sl},$$

$$\mathcal{H}_{\rm eff}^{\rm had} = \frac{4G_F}{\sqrt{2}} \sum_{p=u,c} \lambda_p \Big[C_1 Q_1^p + C_2 Q_2^p + \sum_{i=3\ldots 6} C_i P_i + C_{8g} Q_{8g} \Big],$$

$$\mathcal{H}_{\rm eff}^{\rm sl} = -\frac{4G_F}{\sqrt{2}} \lambda_t \Big[C_7 Q_{7\gamma} + C_7' Q_{7\gamma}' + C_9 Q_{9V} + C_9' Q_{9V}' + C_{10} Q_{10A} + C_{10}' Q_{10A}' + C_S Q_S + C_S' Q_S' + C_P Q_P + C_P' Q_P' + C_T Q_T + C_T' Q_T' \Big].$$

The operators P_i are given in [8], the Q_i are defined as

$$Q_{7\gamma} = \frac{e}{16\pi^2}\, \hat{m}_b\, \bar{s}\sigma_{\mu\nu} P_R F^{\mu\nu} b\,,$$

$$Q_{9V} = \frac{\alpha_{\rm em}}{4\pi} (\bar{s}\gamma_\mu P_L b)(\bar{l}\gamma^\mu l)\,,$$

$$Q_S = \frac{\alpha_{\rm em}}{4\pi} \frac{\hat{m}_b}{m_W} (\bar{s} P_R b)(\bar{l} l)\,,$$

$$Q_T = \frac{\alpha_{\rm em}}{4\pi} \frac{\hat{m}_b}{m_W} (\bar{s}\sigma_{\mu\nu} P_R b)(\bar{l}\sigma^{\mu\nu} P_R l)\,,$$

$$Q_{8g} = \frac{g_s}{16\pi^2}\, \hat{m}_b\, \bar{s}\sigma_{\mu\nu} P_R G^{\mu\nu} b\,,$$

$$Q_{10A} = \frac{\alpha_{\rm em}}{4\pi} (\bar{s}\gamma_\mu P_L b)(\bar{l}\gamma^\mu \gamma^5 l)_A\,,$$

$$Q_P = \frac{\alpha_{\rm em}}{4\pi} \frac{\hat{m}_b}{m_W} (\bar{s} P_R b)(\bar{l}\gamma^5 l)\,,$$

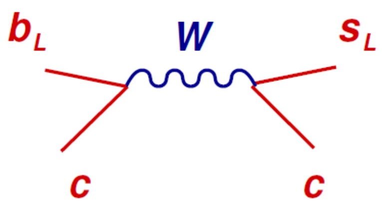
And the primed operators Q_i' are obtained from these by $P_R \to P_L$; $P_L \to P_R$ in the quark bilinears.

[7] Jäger, S. and Martin Camalich, J.,JHEP05(2013)043; P.R.L.113.241802.

[8] Chetyrkin, Konstantin G. and Misiak, Mikolaj and Munz, ManfredPhys. Lett. B 400 (1997) 206.

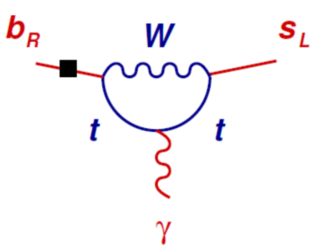
Operators structure and Feynman diagrams in SM

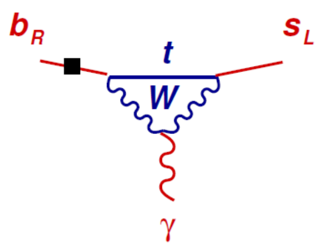
Charged Current:



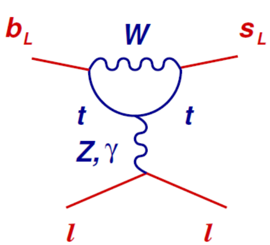
$$G_F\, V_{cb}\, V^*_{cs}\, C_2\, \bar{c}_L \gamma^\mu b_L\, \bar{s}_L \gamma_\mu c_L$$

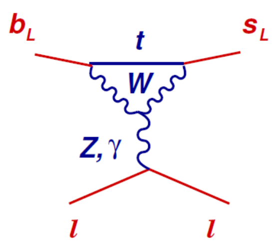
Flavor Changing Neutral Currents(FCNC):

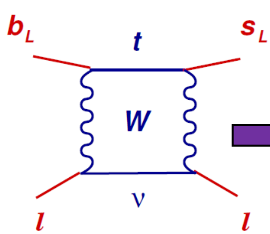




$$\frac{e}{4\pi^2}\, G_F\, V_{tb}\, V^*_{ts}\, m_b\, C_7\, \bar{s}_L \sigma_{\mu\nu} b_R\, F^{\mu\nu}$$







$$G_F\, V_{tb}\, V^*_{ts}\, \frac{\alpha}{4\pi}\, C_{9(10)}\, \bar{s}_L \gamma^\mu b_L\, \bar{\ell} \gamma_\mu (\gamma_5) \ell$$

Wilson coefficient $C_i(\mu)$ are calculated in perturbative theory at $\mu = m_W$ and rescaled to $\mu = m_b$.

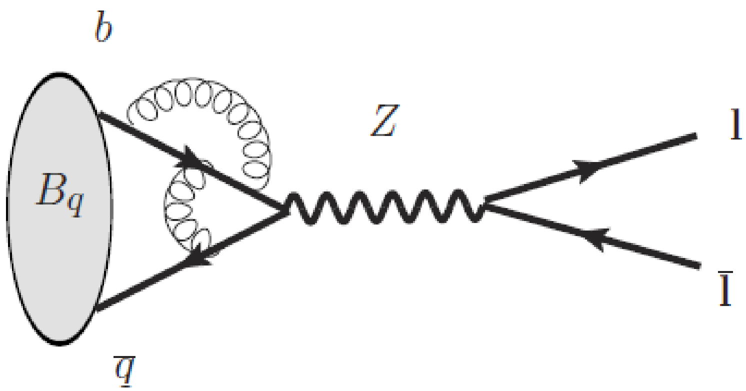
Interesting decay channels to $b \to s\, l\, l$ decays

Table 1. Effective couplings $C^{(\prime)}_{7,9,10}$ contributing to $b \to s l^+ l^-$ transitions and sensitivity of the various radiative and (semi-)leptonic $B_{(s)}$ decays to them.

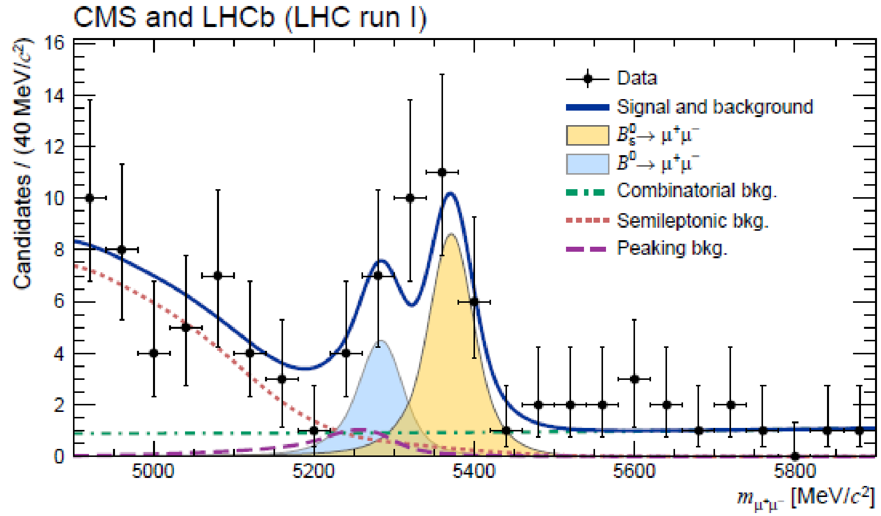
processes	$C_7^{(\prime)}$	$C_9^{(\prime)}$	$C_{10}^{(\prime)}$
$B \to K^* \gamma$	$\surd$		
$B_s \to \mu^+ \mu^-$			$\surd$
$B \to K^{(*)} \mu^+ \mu^-$	$\surd$	$\surd$	$\surd$

- Radiative decays are only sensitive to $C_7^{(\prime)}$.
- B_s-> μ+ μ- is an excellent choice to constrain $C_{10}^{(\prime)}$.
- For study of lepton-universality, we used these decay channels except BR(B->K*γ). Note that BR(B->K*γ) can fix better soft form factors.

Phenomenological consequences of $Bs -> \mu + \mu -$



CMS and LHCb combined arXiv: 1411.4413



Branching ratio:

$$\mathrm{Br}(B_s \to \mu^+\mu^-)^{\mathrm{SM}} = \tau_{B_s}\frac{G_F^2\alpha^2}{16\pi^3}|V_{tb}V_{ts}^*|^2 m_{B_s} m_\mu^2 \beta_\mu(m_{B_s}^2)|\mathbf{C}_{10}|^2 f_{B_s}$$

Define R:

$$R = \frac{\mathrm{Br}}{\mathrm{Br}^{\mathrm{SM}}} = \frac{C_{10}^{\mathrm{SM}} + \delta C_{10} - \delta C_{10}'}{C_{10}^{\mathrm{SM}}}$$

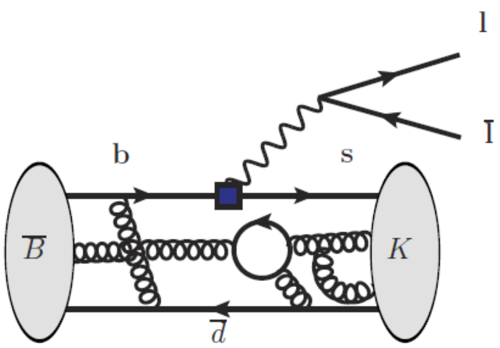
$$C_{10}^{SM} = -4.279$$

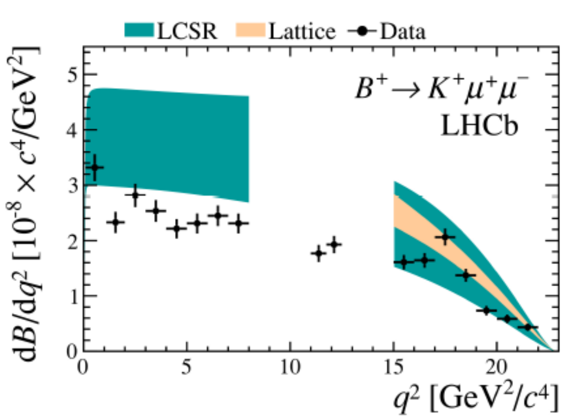
- **The decay channel is very clean.(Only include a uncertain parameter f_{Bs}.)**
- **Very rare ! (GIM and helicity suppression)**

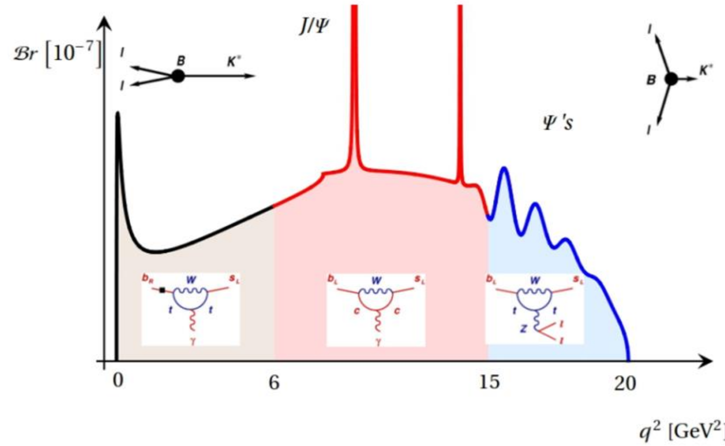
Phenomenological consequences of *B->Kℓℓ*

B->kℓℓ: three body decay mode:

LHCb JHEP06(2014)133, JHEP05(2014)082, PRL111 (2013)112003,. . .







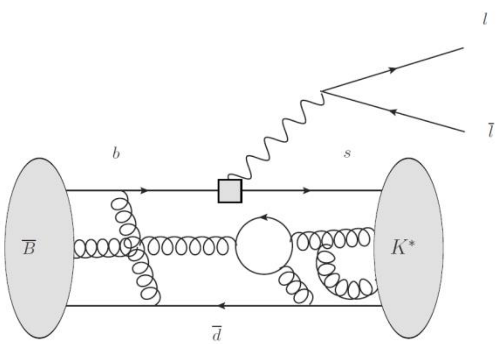
The differential decay rate:

$$\frac{d\Gamma_K}{dq^2} = \mathcal{N}_K |\vec{k}|^3 f_+(q^2)^2 \left(\left| C_{10}^{\ell} + C_{10}^{\prime\ell} \right|^2 + \left| C_9^{\ell} + C_9^{\prime\ell} + 2\frac{m_b}{m_B + m_K} C_7 \frac{f_T(q^2)}{f_+(q^2)} - 8\pi^2 h_K \right|^2 \right)$$
$$+ \mathcal{O}\left(\frac{m_\ell^4}{q^4}\right) + \frac{m_\ell^2}{m_B^2} \times \mathcal{O}\left(\alpha_s, \frac{q^2}{m_B^2} \times \frac{\Lambda}{m_b}\right),$$

- Kinematics range for the 3-bady decay is $q^2 \in [4m_l^2, (m_B - m_K)^2]$.
- There are very complicated nonperturbative problems.
- Charmonium region cannot be calculated by perturbative theory.

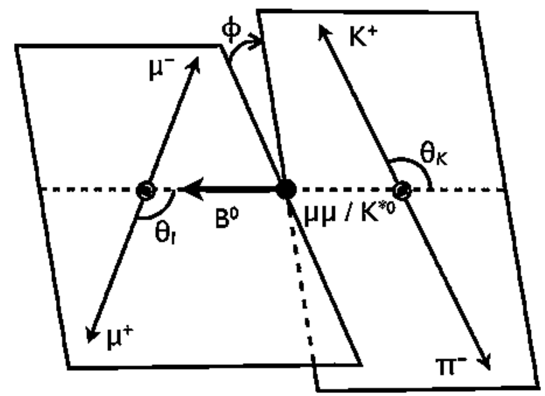
Phenomenological consequences of $B \to K^* l\, l$

B->K*(Kπ)ℓℓ: four body decay mode:



- **Large-recoil region (low q²)**
  - **Dominant effect of the photon pole;**
  - **QCD factorization , LCSR, heavy quark limit (power corrections).**
- **Charmonium region**
  - **Dominated by long-distance (hadronic) effects.**
- **Low-recoil region (high q²)**
  - **Dominated by semi-lepton operators.**

Kinematics of 4-body decay:



$$F_L = S_{1c}$$

$$P_1 = \frac{2\,S_3}{(1-F_L)} = A_T^{(2)},$$

$$P_2 = \frac{2}{3}\frac{A_{FB}}{(1-F_L)},$$

$$P_3 = \frac{-S_9}{(1-F_L)},$$

$$P'_{4,5,8} = \frac{S_{4,5,8}}{\sqrt{F_L(1-F_L)}},$$

$$P'_6 = \frac{S_7}{\sqrt{F_L(1-F_L)}}.$$

$$\frac{d^{(4)}\Gamma}{dq^2\, d(\cos\theta_l) d(\cos\theta_k) d\phi} = \frac{9}{32\,\pi}$$

$$\times\Big(I_1^s \sin^2\theta_k + I_1^c \cos^2\theta_k + (I_2^s \sin^2\theta_k + I_2^c \cos^2\theta_k)\cos 2\theta_l$$
$$+ I_3 \sin^2\theta_k \sin^2\theta_l \cos 2\phi + I_4 \sin 2\theta_k \sin 2\theta_l \cos\phi$$
$$+ I_5 \sin 2\theta_k \sin\theta_l \cos\phi + (I_6^s \sin^2\theta_k + I_6^c \cos^2\theta_K)\cos\theta_l$$
$$+ I_7 \sin 2\theta_k \sin\theta_l \sin\phi + I_8 \sin 2\theta_k \sin 2\theta_l \sin\phi + I_9 \sin^2\theta_k \sin^2\theta_l \sin 2\phi\Big).$$

$$S_i = (I_i + \bar{I}_i) \Big/ \left(\frac{d\Gamma}{dq^2} + \frac{d\bar{\Gamma}}{dq^2}\right)$$

$$A_i = (I_i - \bar{I}_i) \Big/ \left(\frac{d\Gamma}{dq^2} + \frac{d\bar{\Gamma}}{dq^2}\right).$$

27 hadronic paramenters in low q^2:

Phys. Rev., D93(1):014028,2016, JHEP, 05:043, 2013

Table 2: 27 hadronic parameters

QCDf(11)	$\mu, \xi_\perp(0), \xi_\parallel(0), f_{K^*}, a1_\perp, a2_\perp(0), a1_\parallel(0), a2_\parallel(0), \omega_0, r_\perp, r_\parallel$
Power Corrections(8)	$V_-(\|a\|_{\max}), V_-(\|b\|_{\max}), V_+(\|a\|_{\max}), V_+(\|b\|_{\max}), T_+(\|b\|_{\max}), V_0(\|b\|_{\max}), T_0(\|a\|_{\max}), T_0(\|b\|_{\max})$
Charm contributions(8)	$h_-\|_{c\bar{c}}(\|a\|_{\max}), h_-\|_{c\bar{c}}(\|b\|_{\max}), \phi_-\|_{c\bar{c}}, h_+\|_{c\bar{c}}(\|a\|_{\max}), h_+\|_{c\bar{c}}(\|b\|_{\max}), \phi_+\|_{c\bar{c}}, h_0\|_{c\bar{c}}, \phi_0\|_{c\bar{c}}$

However, in high q^2 region, uncertainties are from 7 form factors and charm contributions but not from power corrections.

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Numerical details

To limit the range of NP degree of freedom, we can do a χ2 fit.

- ## χ^2 fit

$$\tilde{\chi}^2(\vec{C},\, \vec{y}) = \chi^2_{\rm exp}(\vec{C},\, \vec{y}) + \chi^2_{\rm th}(\vec{y}).$$

The experiment term is taken in Gaussian form

$$\chi^2_{\rm exp} = \frac{(\vec{O}^{\rm exp} - \vec{O}^{\rm th})^2}{\delta \vec{O}^2_{\rm exp}}$$

The theory term is also taken in Gaussian form

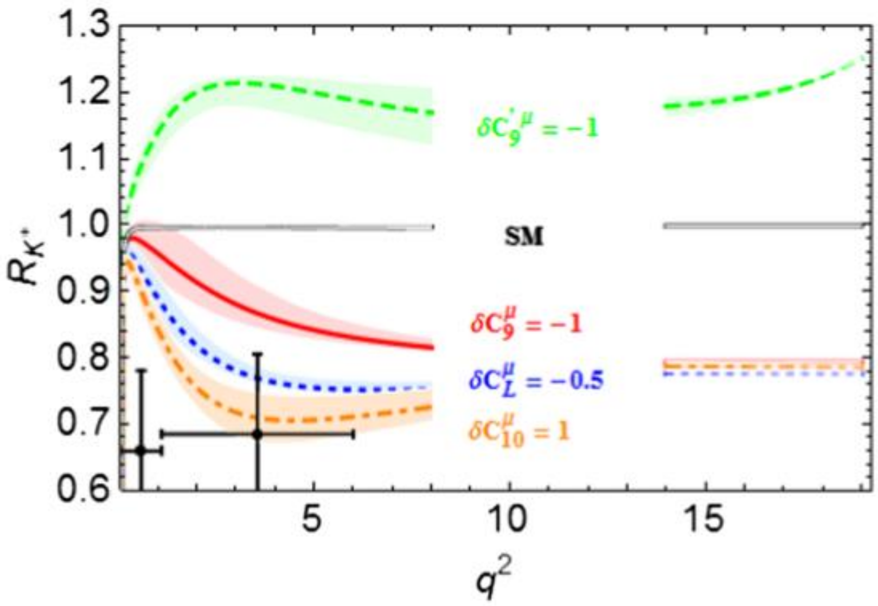
$$\chi^2_{\rm th}(\vec{y}) = \sum_i \left(\frac{y_i - \bar{y}_i}{\delta y_i} \right)^2$$

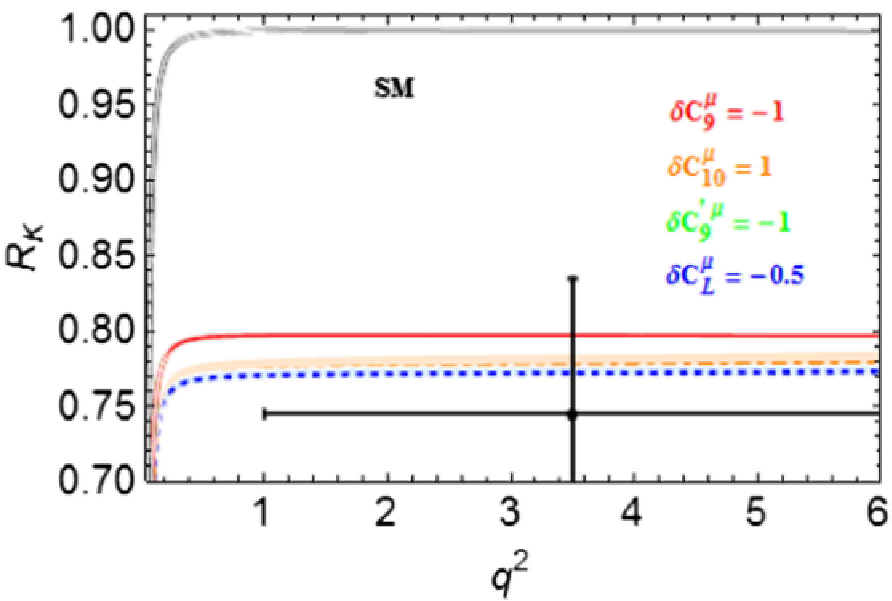
Where O are observables, C are relevant Wilson coefficients and y are 27 hadronic parameters.

- ## Experiment data

(i R. Aaij et al. (LHCb Collaboration), J. High Energy Phys. 02 (2016) 104;
(ii S. Wehle et al. (Belle Collaboration), Phys. Rev. Lett. 118, 111801 (2017);
(iii ATLAS Collaboration, Report No. ATLAS-CONF-2017- 023, 2017;
(iv M. Dinardo, in 52nd Rencontres de Moriond, La Thuile, March 18-25, 2017 (2017), https://indico.in2p3.fr/ event/13763/session/10/contribution/108/material/slides/0.pdf.;
(v W. Altmannshofer, C. Niehoff, and D. M. Straub, J. High Energy Phys. 05 (2017) 076.

Predictions in the SM and in selected NP scenarios





$$\delta C_L = \delta C_9 = -\delta C_{10}$$

- **we conclude that only the operators O_9,O_{10} instead of O_9',O_{10}' are favored by the data.**

3 steps

To better constrain NP degree of freedom better, let us go step by step.

Fit 1: Fits only to R_K and R_{K^*}

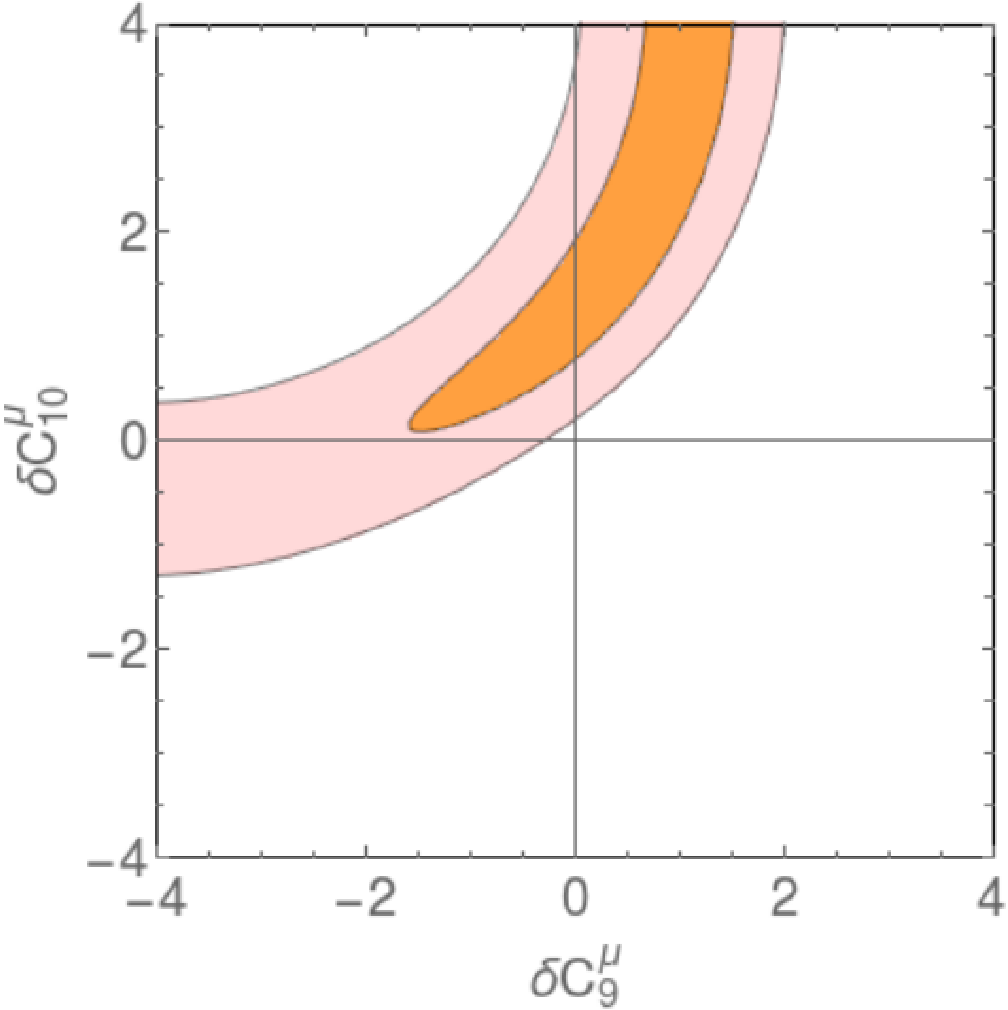
↓

Fit 2: Fits only to R_K ,R_{K^*} and R($Bs -> \mu + \mu -$)

↓

Fit 3: Fits only to R_K ,R_{K^*},R($Bs -> \mu + \mu -$),Br($B -> K^* \gamma$) and $B -> K^* \mu \mu$ data

Fit 1: Fits only to R_K and R_{K*}



Data(3):

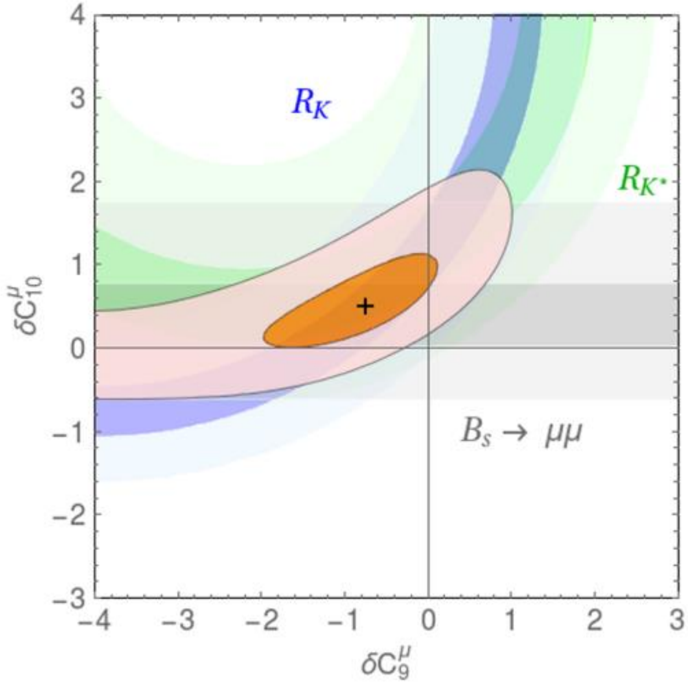
R_K bin[1,6] GeV^2

R_{K*} bin[0.045,1.1] GeV^2

bin[1.1,6] GeV^2

- **Both δC_9 and δC_{10} have no boundary.**

Fit 2: Fits only to R_K, R_{K*} and R($Bs \to \mu + \mu -$)



Data(4):

R_K bin[1,6] GeV^2

R_{K*} bin[0.045,1.1] GeV^2

bin[1.1,6] GeV^2

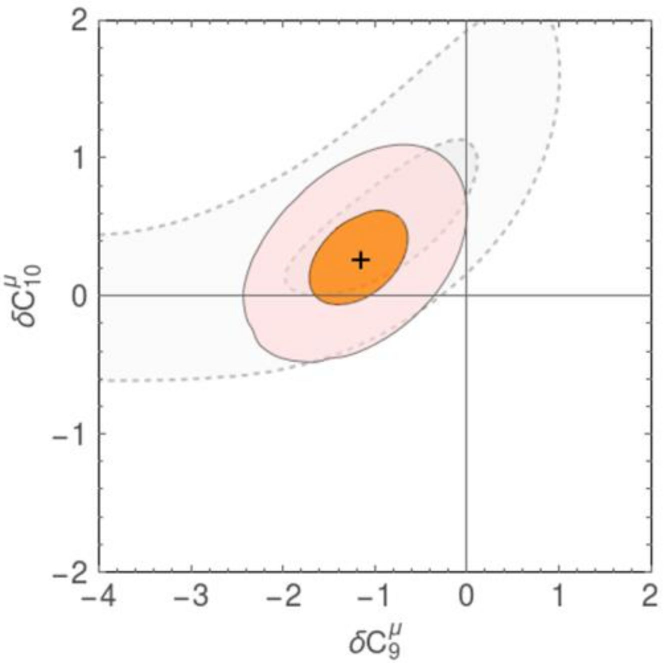
R(Bs-> μ+ μ-)

$$\text{Pull} = \sqrt{\chi^2_{\text{min,SM}} - \chi^2_{\text{min,NP}}}$$

Coefficient	Best fit	χ^2_{min}	p-value	SM exclusion [σ]	1σ range	3σ range
δC_9^{μ}	−1.64	5.65	0.130	3.87	[−2.31, −1.12]	[<−4, −0.31]
δC_{10}^{μ}	0.91	4.98	0.173	3.96	[0.66, 1.18]	[0.20, 1.85]
δC_L^{μ}	−0.61	3.36	0.339	4.16	[−0.78, −0.46]	[−1.14, −0.16]
Coefficient	Best fit	χ^2_{min}	p-value	SM exclusion [σ]	Parameter ranges	
$(\delta C_9^{\mu}, \delta C_{10}^{\mu})$	(−0.76, 0.54)	3.31	0.191	3.76	$C_9^{\mu} \in [-1.50, -0.16]$	$C_{10}^{\mu} \in [0.18, 0.92]$

- **Now, we can see that δC_{10} is bounded but δC_9 still not.**
- **We note that significance of the SM exclusion in the fits is close to 4σ.**

Fit 3: Fits to R_K and R_{K^*}, $R(Bs -> \mu^+ \mu^-)$, Br($B -> K^* \gamma$) and $B -> K^* \mu^+ \mu^-$ data



Data(65):

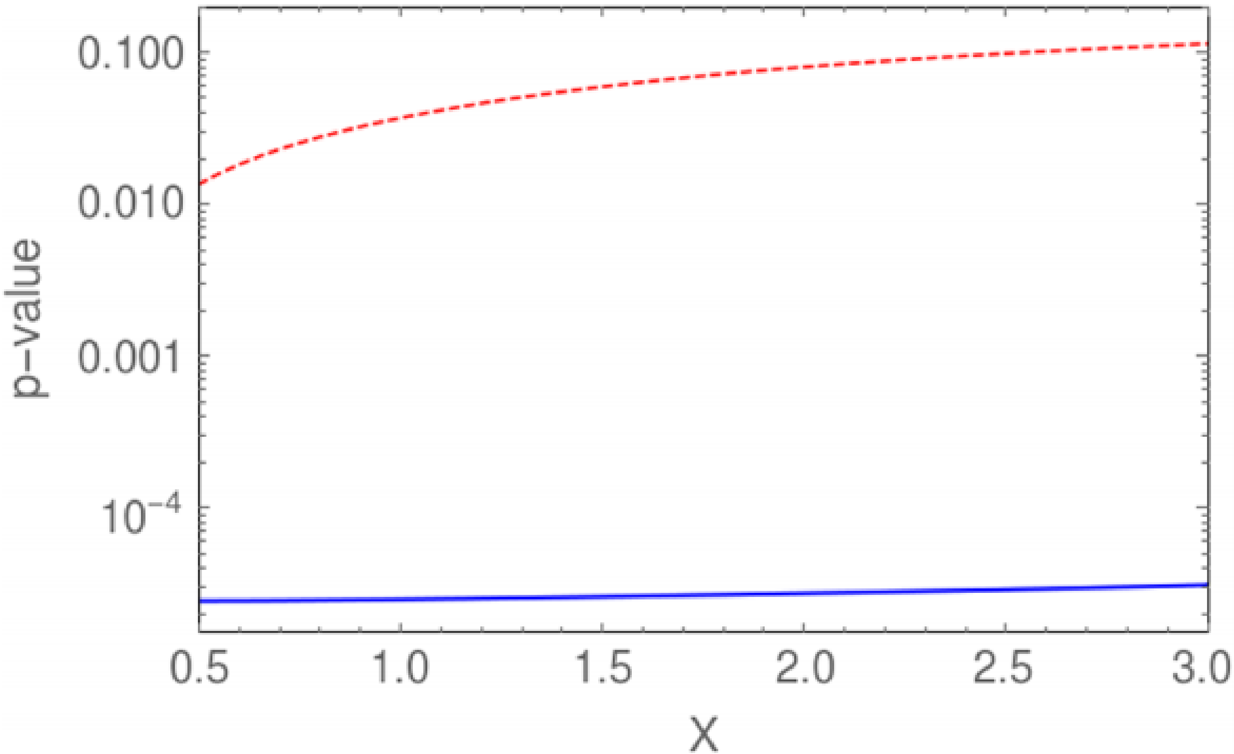
- R_K bin[1,6] GeV^2
- R_{K^*} bin[0.045,1.1] GeV^2
  bin[1.1,6] GeV^2
- R(Bs-> μ+ μ-)
- BR(B->K*γ)
- All angular observables from LHCb, LTLAS,CMS, Belle: F_L,P_1,P_2,P_3,P_4',P_5',P_6',P_8'.

$$\chi^2_{\rm min,SM} = 81.1$$

Coefficient	Best fit	$\chi^2_{\rm min}$	p-value	SM exclusion [σ]	1σ range	3σ range
δC_9^{μ}	−1.37	61.98 [64 dof]	0.548	4.37	[−1.70, −1.03]	[−2.41, −0.41]
δC_{10}^{μ}	0.60	71.72 [64 dof]	0.237	3.06	[0.40, 0.82]	[−0.01, 1.28]
δC_L^{μ}	−0.59	63.62 [64 dof]	0.490	4.18	[−0.74, −0.44]	[−1.05, −0.16]
Coefficient	Best fit	$\chi^2_{\rm min}$	p-value	SM exclusion [σ]	Parameter ranges	
$(\delta C_9^{\mu}, \delta C_{10}^{\mu})$	(−1.15, 0.28)	60.33 [63 dof]	0.572	4.17	$C_9^{\mu} \in [-1.54, -0.81]$	$C_{10}^{\mu} \in [0.06, 0.50]$

- We note that significance of the SM exclusion in the fits is about 4σ.
- δC_9 is negative. However, the value of δC_{10} is poorly determined by the global fit.

Robustness of fit with respect to hadronic uncertainties



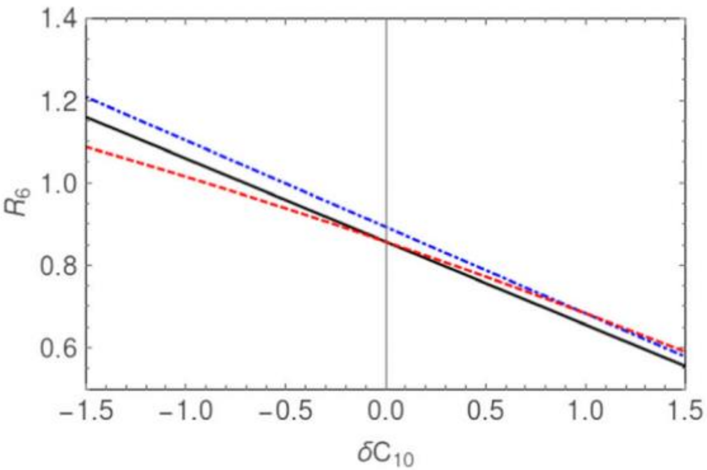
X-dependence study

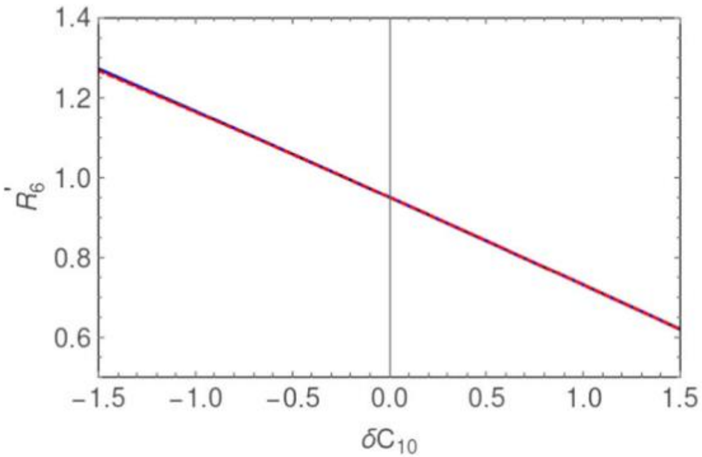
Solid blue line:
Fits only to RK and RK*

Dashed red line:
Fits to all data

- **The results are shown in the figure by the blue solid curve which demonstrates the stability(but dashed red line not), with respect to the hadronic uncertainties in the semileptonic decays, of the fits to the lepton-universality ratios.**

Precision probes of a lepton-nonuniversal C_{10}

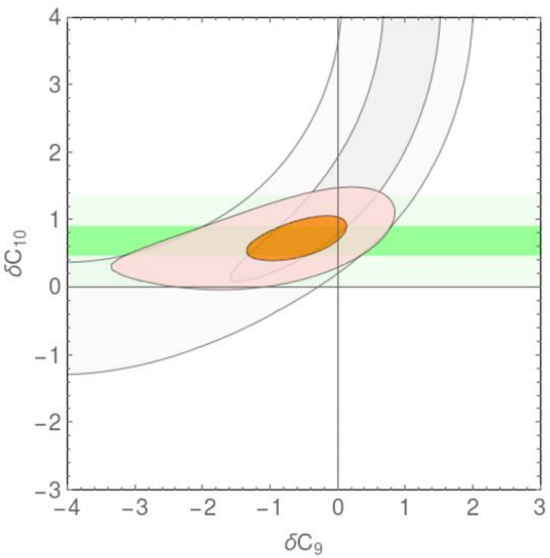




$\delta C_9=0$

$\delta C_9= -\delta C_{10}$

$\delta C_9= -1$



Data(4):

- **R_K bin[1,6] GeV^2**
- **R_{K^*} bin[0.045,1.1]GeV^2**
- **bin[1.1,6] GeV^2**
- **R_6' bin[0.045,1.1] GeV^2**

$$H_V(\lambda) = -iN\left[\tilde{V}_\lambda(q^2)C_9 + \frac{2\,m_b m_B}{q^2}\tilde{T}_\lambda(q^2)C_7 - \frac{16\pi^2 m_B^2}{q^2}h_\lambda(q^2)\right]$$

$$R_6[a,b] = \frac{\int_a^b \Sigma_6^\mu dq^2}{\int_a^b \Sigma_6^e dq^2}$$

$$\approx \frac{C_{10}^\mu}{C_{10}^e} \times \frac{\int_a^b |\vec{k}|q^2\beta_\mu^2 \mathrm{Re}[H_{V-}^{(\mu)}(q^2)]V_-(q^2)}{\int_a^b |\vec{k}|q^2 \mathrm{Re}[H_{V-}^{(e)}(q^2)]V_-(q^2)}$$

$$P_2 = \frac{\Sigma_6}{8\Sigma_{2s}} \qquad R_6' = \langle P_2^{(\mu)}\rangle / \langle P_2^{(e)}\rangle$$

- **These constructed observables are almost exclusively sensitive to C_{10} .**
- **Experimentally, these observables can be measured by LHCb and Belle.**

Outline

- Background
- Purpose
- Theoretical framework
- Results and Discussions
- Summary and Outlook

Summary

- We found that only O_9,O_{10} can explain the experiment data;
- We obtained that significance of the SM exclusion in our fits is about 4σ;
- Finally, C_{10} is poorly determined by global fit but we also discuss some observables which are almost only sensitive to C_{10}. And it is feasible to measure these observations at present.
- … …

Outlook

- ✓ **In the next few years, with the collection of more data at the LHCb and improvement of experimental precision, we will continually update our results.**

- ✓ **In addition, new theoretical work on the theoretical side will be needed. Such work involves assessing better uncertainties.**

- ✓ **Meantime, it is necessary to continue to find or construct new observables which are only sensitive to C_{10}.**
- ✓ **… …**

Thanks for Your Attention

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