Weak decays of B-meson in the light of the search for new physics

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Contents

Lepton universality in B meson decays

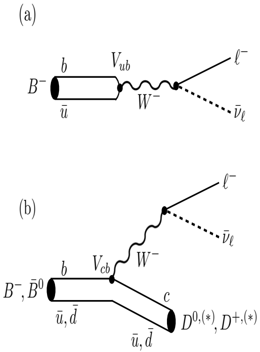
G. Ciezarek et al., "A Challenge to Lepton Universality in B Meson Decays," arXiv:1703.01766 [hep-ex]

- Three generations of leptons in the Standard Model (SM):

$$\begin{pmatrix} \nu_e \\ e^- \end{pmatrix}, \quad \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix}, \quad \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}.$$

- The SM assumes that the interactions of leptons are universal, i.e. the same for the three generations.
- The most precise tests in the decays $K \to e\bar{\nu}_e$ vs. $K \to \mu\bar{\nu}_\mu$ have confirmed $\mu - e$-universality.
- Recent studies of (semi)leptonic B-meson decays $B^- \to \tau^-\bar{\nu}_\tau$ and $\bar{B} \to D^{(*)}\ell^-\bar{\nu}_\ell$, with $\ell = e, \mu, \tau$ and $D^{(*)} = D, D^*$ have shown the possible violation of the lepton universality in τ-sector.

B-meson (semi)leptonic decays in the SM



(a) $B^- \to \tau^- \bar{\nu}_\tau$ with a purely leptonic final state and

(b) $\bar{B} \to D^{(*)} \ell^- \bar{\nu}_\ell$ involving a charm meson and lepton pair and mediated by a vector boson (W^-).

Standard model predictions of B-meson decay rates

- For purely leptonic B-decays, the SM prediction of the total decay rate Γ, which depends critically on the lepton mass squared m_ℓ^2, is

$$\Gamma^{\rm SM}(B^- \to \ell^- \bar{\nu}_\ell) = \frac{G_F^2\ m_B\ m_\ell^2}{8\pi} |V_{ub}|^2 \left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 \times f_B^2$$

- All hadronic effects, due to the binding of quarks inside the meson, are encapsulated in the decay constant f_B.
- Recent lattice QCD calculations predict $f_B = (0.191 \pm 0.009)$ GeV.
- The branching fraction is

$$\mathcal{B}^{\rm SM}(B^- \to \tau^- \bar{\nu}_\tau) = (0.75 {\pm}^{0.10}_{0.05}) \times 10^{-4}.$$

- Decays to the e^- and μ^- are strongly suppressed.

Standard model predictions of B-meson decay rates

- **The differential decay rate, $d\Gamma$, for semileptonic decays involving $D^{(*)}$ mesons depends on both m_ℓ^2 and q^2, the invariant mass squared of the lepton pair**

$$\frac{d\Gamma^{\rm SM}(\bar{B} \to D^{(*)}\ell^- \bar{\nu}_\ell)}{dq^2} = \underbrace{\frac{G_F^2\ |V_{cb}|^2\ |p^*_{D^{(*)}}|\ q^2}{96\pi^3 m_B^2}\left(1 - \frac{m_\ell^2}{q^2}\right)^2}_{\text{universal and phase space factors}}$$

$$\times \underbrace{\left[(|H_+|^2 + |H_-|^2 + |H_0|^2)\left(1 + \frac{m_\ell^2}{2q^2}\right) + \frac{3m_\ell^2}{2q^2}|H_s|^2\right]}_{\text{hadronic effects}}. \qquad (1)$$

- **$p^*_{D^{(*)}}$ is the 3-momentum of the hadron in the B rest frame. The four helicity amplitudes $H_\pm, H_0, H_s$ capture the impact of hadronic effects. They depend on the spin of the charm meson and on q^2: $m_\ell^2 \leq q^2 \leq (m_B - m_{D^*})^2$.**

Standard model predictions of B-meson decay rates

- **Measurements of the ratios of semileptonic branching fractions remove the dependence on $|V_{cb}|$, lead to a partial cancellation of theoretical uncertainties related to hadronic effects, and reduce of the impact of experimental uncertainties.**
- **Current SM predictions**

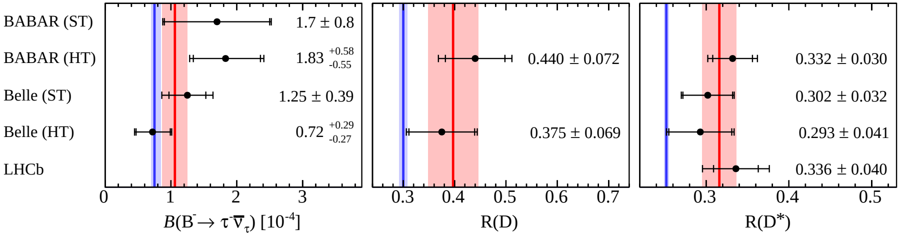
$$\mathcal{R}_{D}^{SM} = \frac{\mathcal{B}(\bar{B} \to D\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D\ell^-\bar{\nu}_\ell)} = 0.300 \pm 0.008$$

$$\mathcal{R}_{D^*}^{SM} = \frac{\mathcal{B}(\bar{B} \to D^*\tau^-\nu_\tau)}{\mathcal{B}(\bar{B} \to D^*\ell^-\nu_\ell)} = 0.252 \pm 0.003.$$

Here $\ell = e$ or μ.

Measurements vs SM predictions

G. Ciezarek et al. "A Challenge to Lepton Universality in B Meson Decays," arXiv:1703.01766



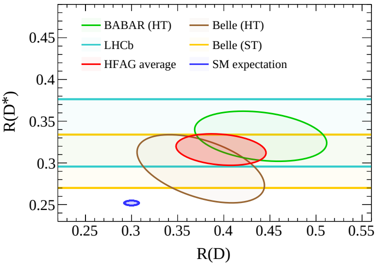
- **The data points indicate statistical and total uncertainties.**
- **ST and HT refer to the measurements with semileptonic and hadronic tags, respectively.**
- **The average values of the measurements and their combined uncertainties, obtained by the Heavy Flavor Averaging Group (HFAG), are shown in red as vertical lines and bands, and the expectations from the SM calculations are shown in blue.**

Measurements vs SM predictions

The averages of the measurements (HFAG) are

$$\mathcal{R}(D) = 0.397 \pm 0.040_{\text{stat}} \pm 0.028_{\text{syst}},$$
$$\mathcal{R}(D^*) = 0.316 \pm 0.016_{\text{stat}} \pm 0.010_{\text{syst}}.$$

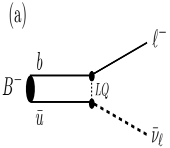
The combined difference between the measured and expected values has a significance of about 4σ.



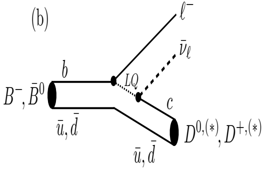
R(D) and R(D*) measurements: Results from BABAR, Belle, and LHCb, their values and 1-σ contours. The average calculated by the HFAG is compared to SM predictions.

Theoretical attempts to explain

- **A charged Higgs boson $\mathbf{H^-}$ in two-Higgs doublet models. The $\mathbf{H^-}$ would mediate weak decays, similar to the $\mathbf{W^-}$, but couple differently to leptons of different mass.**
- **Another solution might be leptoquarks, hypothetical particles with both electric and color charges that allow transitions from quarks to leptons and vice versa.**



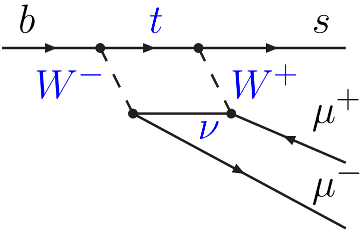
(a) $\mathbf{B^- \to \tau^- \bar{\nu}_\tau}$ via leptoquark.

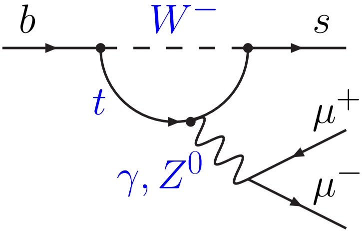


(b) $\mathbf{\bar{B} \to D^{(*)} \tau^- \bar{\nu}_\tau}$ via leptoquark.

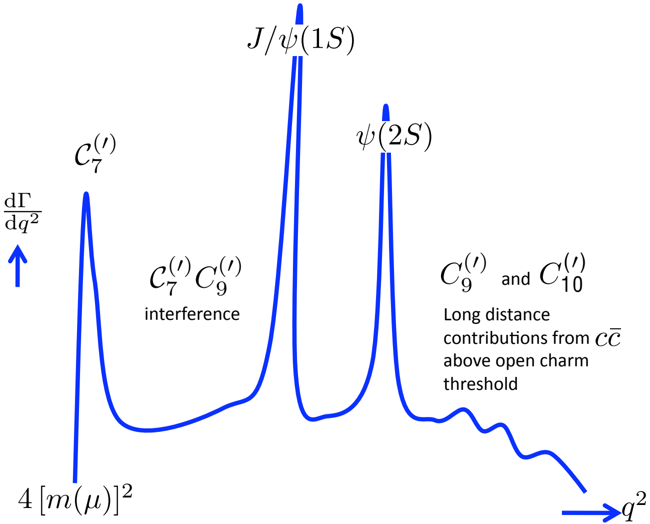
Rare decays of B meson

- **Flavor-Changing-Neutral-Current (FCNC) processes, where a quark changes its flavor without altering its electric charge, are forbidden at tree level in the Standard Model (SM).**
- **FCNC processes proceed via loop diagrams. Thus they are sensitive to new unobserved particles.**
- **$\mathbf{b} \to \mathbf{s}\ell^+\ell^-$-transitions are excelent tools to study the rare processes.**

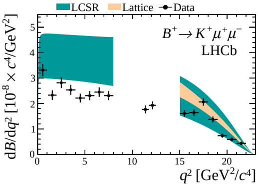




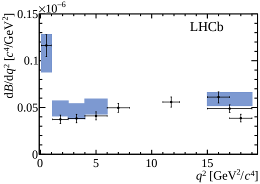
$B^0 \to K^{*0}\mu^+\mu^-$ differential branching fraction



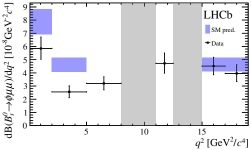
Differential branching fractions



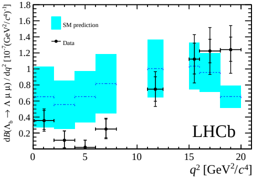
$B^+ \to K^+\mu^+\mu^-$



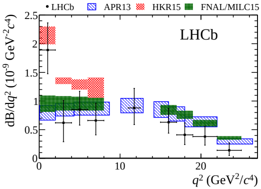
$B^0 \to K^{*0}\mu^+\mu^-$



$B_s^0 \to \phi\mu^+\mu^-$

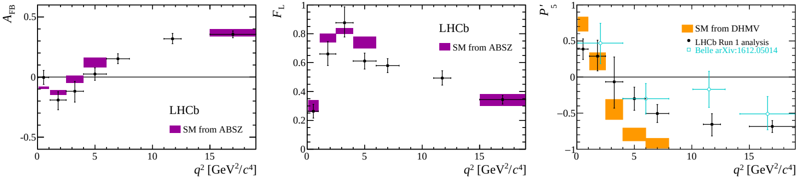


$\Lambda_b^0 \to \Lambda\mu^+\mu^-$

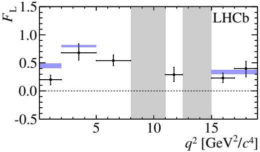


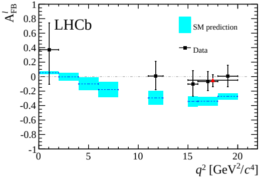
$B^+ \to \pi^+\mu^+\mu^-$

Angular observables



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





$\mathbf{B_s^0 \to \phi\mu^+\mu^-}$

$\mathbf{\Lambda_b^0 \to \Lambda\mu^+\mu^-}$

Covariant quark confined model

- **Main assumption: hadrons interact via quark exchange only**
- **Interaction Lagrangian**

$$\mathcal{L}_{\rm int} = g_H \cdot H(x) \cdot J_H(x)$$

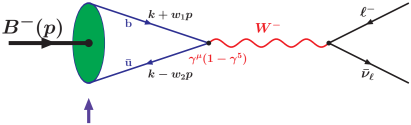
- **Quark currents**

$$J_M(x) = \int dx_1 \int dx_2\, F_M(x; x_1, x_2) \cdot \bar{q}^a_{f_1}(x_1)\, \Gamma_M\, q^a_{f_2}(x_2) \qquad \text{Meson}$$

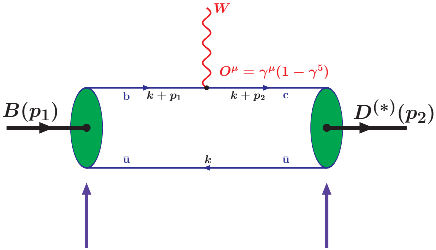
$$J_B(x) = \int dx_1 \int dx_2 \int dx_3\, F_B(x; x_1, x_2, x_3) \qquad \text{Baryon}$$
$$\times\, \Gamma_1\, q^{a_1}_{f_1}(x_1) \left[\varepsilon^{a_1 a_2 a_3} q^{T\, a_2}_{f_2}(x_2) C\, \Gamma_2\, q^{a_3}_{f_3}(x_3)\right]$$

$$J_T(x) = \int dx_1 \ldots \int dx_4\, F_T(x; x_1, \ldots, x_4) \qquad \text{Tetraquark}$$
$$\times \left[\varepsilon^{a_1 a_2 c} q^{T\, a_1}_{f_1}(x_1)\, C\Gamma_1\, q^{a_2}_{f_2}(x_2)\right] \cdot \left[\varepsilon^{a_3 a_4 c} \bar{q}^{T\, a_3}_{f_3}(x_3)\, \Gamma_2 C\, \bar{q}^{a_4}_{f_4}(x_4)\right]$$

Matrix elements



$\phi_B\left(-k^2\right)$ $\quad w_1 = \frac{m_b}{m_b+m_u}, \quad w_2 = 1 - w_1$



$\phi_B\left(-\left(k + w_{bu}\, p_1\right)^2\right)$ $\quad \phi_{D^{(*)}}\left(-\left(k + w_{cu}\, p_2\right)^2\right)$

$w_{bu} = \frac{m_u}{m_b+m_u}$ $\quad w_{cu} = \frac{m_u}{m_c+m_u}$

Infrared confinement

- An example of a scalar one–loop two–point function:

$$\Pi_2(p^2) = \int \frac{d^4k_E}{\pi^2} \frac{e^{-s\,k_E^2}}{[m^2 + (k_E + \frac{1}{2}p_E)^2][m^2 + (k_E - \frac{1}{2}p_E)^2]}$$

where the numerator factor $e^{-s\,k_E^2}$ comes from the product of nonlocal vertex form factors of Gaussian form. k_E, p_E are Euclidean momenta ($p_E^2 = -\,p^2$).

- Doing the loop integration one obtains

$$\Pi_2(p^2) = \int_0^\infty dt \frac{t}{(s+t)^2} \int_0^1 d\alpha\ \exp\left\{-\,t\,[m^2 - \alpha(1-\alpha)p^2] + \frac{st}{s+t}\left(\alpha - \frac{1}{2}\right)^2 p^2\right\}$$

A branch point at $p^2 = 4m^2$.

Infrared confinement

- By introducing a cut-off in the t–integration one obtains

$$\Pi_2^c(p^2) = \int\limits_0^{1/\lambda^2} dt \frac{t}{(s+t)^2} \int\limits_0^1 d\alpha \, \exp\left\{ -t\,[m^2 - \alpha(1-\alpha)p^2] + \frac{st}{s+t}\left(\alpha - \frac{1}{2}\right)^2 p^2 \right\}$$

where the one–loop two–point function $\Pi_2^c(p^2)$ no longer has a branch point at $p^2 = 4m^2$.

- The confinement scenario also allows to include all possible both two-quark and multi-quark resonance states in our calculations.

Model parameters

The values of quark masses m_{q_i}, the infrared cutoff parameter λ and the size parameters Λ_{H_i} have been defined by the fit to the well-known physical observables.

m_u	m_s	m_c	m_b	λ	
0.241	0.428	1.672	5.046	0.181	GeV

Λ_π	Λ_K	Λ_D	Λ_{D_s}	Λ_B	Λ_{B_s}	Λ_{B_c}	Λ_ρ
0.87	1.01	1.60	1.75	1.96	2.05	2.73	0.62

Λ_ω	Λ_ϕ	$\Lambda_{J/\psi}$	Λ_{K^*}	Λ_{D^*}	$\Lambda_{D_s^*}$	Λ_{B^*}	$\Lambda_{B_s^*}$
0.49	0.88	1.74	0.80	1.53	1.56	1.80	1.79

Analyzing New Physics in the decays $B \to D^{(*)}\tau\nu_\tau$

Effective Hamiltonian for the quark-level transition $b \to c\tau^-\bar{\nu}_\tau$.

$$\mathcal{H}_{\rm eff} \propto G_F V_{cb} \left[(1 + V_L)\mathcal{O}_{V_L} + V_R\mathcal{O}_{V_R} + S_L\mathcal{O}_{S_L} + S_R\mathcal{O}_{S_R} + T_L\mathcal{O}_{T_L}\right]$$

where the four-fermion operators are written as

$$\mathcal{O}_{V_L} = (\bar{c}\gamma^\mu P_L b)(\bar{\tau}\gamma_\mu P_L \nu_\tau) \qquad \mathcal{O}_{V_R} = (\bar{c}\gamma^\mu P_R b)(\bar{\tau}\gamma_\mu P_L \nu_\tau)$$

$$\mathcal{O}_{S_L} = (\bar{c}P_L b)(\bar{\tau}P_L \nu_\tau) \qquad \mathcal{O}_{S_R} = (\bar{c}P_R b)(\bar{\tau}P_L \nu_\tau)$$

$$\mathcal{O}_{T_L} = (\bar{c}\sigma^{\mu\nu}P_L b)(\bar{\tau}\sigma_{\mu\nu}P_L \nu_\tau)$$

- **Here,** $\sigma_{\mu\nu} = i\left[\gamma_\mu, \gamma_\nu\right]/2$.
- $P_{L,R} = (1 \mp \gamma_5)/2$ **- the left and right projection operators.**
- $V_{L,R}$, $S_{L,R}$, **and** T_L **- complex Wilson coefficients governing NP.**
- **In the SM:** $V_{L,R} = S_{L,R} = T_L = 0$.
- **Assumption: neutrino is always left handed and NP only affects leptons of the third generation.**

NP form factors

M. A. Ivanov, J. G. Körner and C. T. Tran, Phys. Rev. D 94, no. 9, 094028 (2016)

New form factors to describe NP operators:

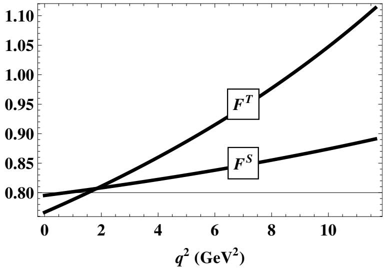
$$\langle D(p_2)|\bar{c}b|\bar{B}^0(p_1)\rangle = (m_1 + m_2)F^S(q^2),$$

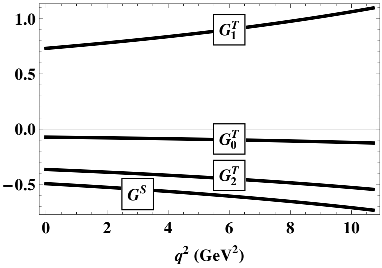
$$\langle D(p_2)|\bar{c}\sigma^{\mu\nu}(1-\gamma^5)b|\bar{B}^0(p_1)\rangle = \frac{iF^T(q^2)}{m_1+m_2}\left(P^\mu q^\nu - P^\nu q^\mu + i\varepsilon^{\mu\nu Pq}\right),$$

$$\langle D^*(p_2)|\bar{c}\gamma^5 b|\bar{B}^0(p_1)\rangle = \epsilon^\dagger_{2\alpha} P^\alpha G^S(q^2),$$

$$\begin{aligned}\langle D^*(p_2)|\bar{c}\sigma^{\mu\nu}(1-\gamma^5)b|\bar{B}^0(p_1)\rangle = & -i\epsilon^\dagger_{2\alpha}\Big[\left(P^\mu g^{\nu\alpha} - P^\nu g^{\mu\alpha} + i\varepsilon^{P\mu\nu\alpha}\right) G_1^T(q^2) \\ & + \left(q^\mu g^{\nu\alpha} - q^\nu g^{\mu\alpha} + i\varepsilon^{q\mu\nu\alpha}\right) G_2^T(q^2) \\ & + \left(P^\mu q^\nu - P^\nu q^\mu + i\varepsilon^{Pq\mu\nu}\right) P^\alpha \frac{G_0^T(q^2)}{(m_1+m_2)^2}\Big]\end{aligned}$$

Form factors for NP operators





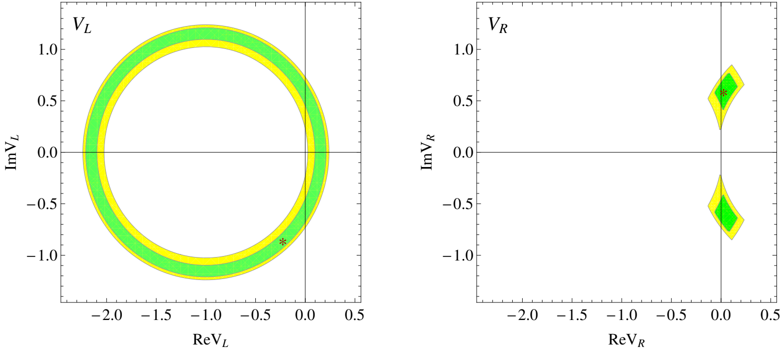
$\bar{B}^0 \to D$ $\bar{B}^0 \to D^*$

NP form factors in the full momentum transfer range

$$0 \leq q^2 \leq q^2_{max} = (m_{\bar{B}^0} - m_{D^{(*)}})^2$$

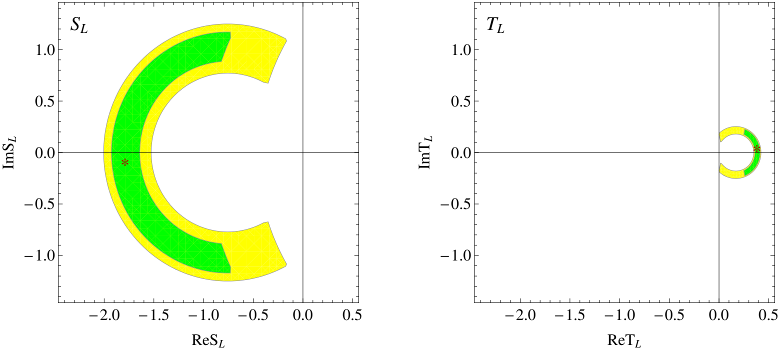
Allowed regions for NP couplings

Assuming that besides the SM contribution, only one of the NP operators is switched on at a time, and NP only affects the tau modes.



The allowed regions of the Wilson coefficients $V_{L,R}$ within 2σ (green, dark) and 3σ (yellow, light).
The best fit value in each case is denoted with the symbol $*$.

Allowed regions for NP couplings



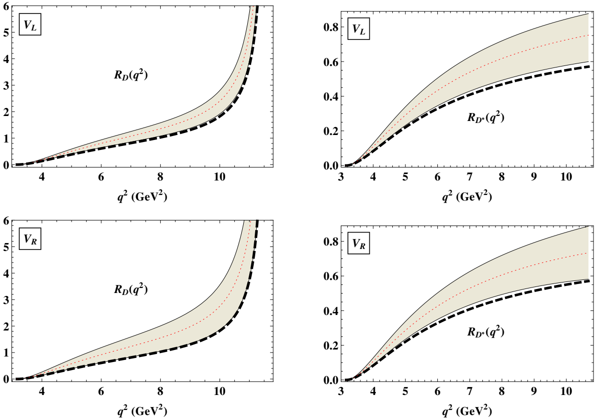
The allowed regions of the Wilson coefficients S_L, and T_L within 2σ (green, dark) and 3σ (yellow, light).

Allowed regions for NP couplings

- It is important to note that while determining these regions, we also take into account a theoretical error of 10% for the ratios $R(D^{(*)})$.
- The operator $\mathcal{O}_{S_R}$ is excluded at 2σ and is not presented here.
- In each allowed region at 2σ we find the best-fit value for each NP coupling.

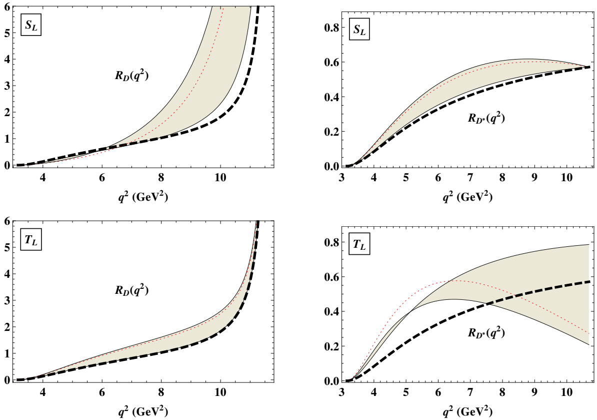
$$\begin{aligned} V_L &= -1.33 + i\,1.11, \qquad V_R = 0.03 - i\,0.60, \\ S_L &= -1.79 - i\,0.22, \qquad T_L = 0.38 - i\,0.06. \end{aligned}$$

Ratios of branching fractions $R_D(q^2)$ (left) and $R_{D^*}(q^2)$ (right)



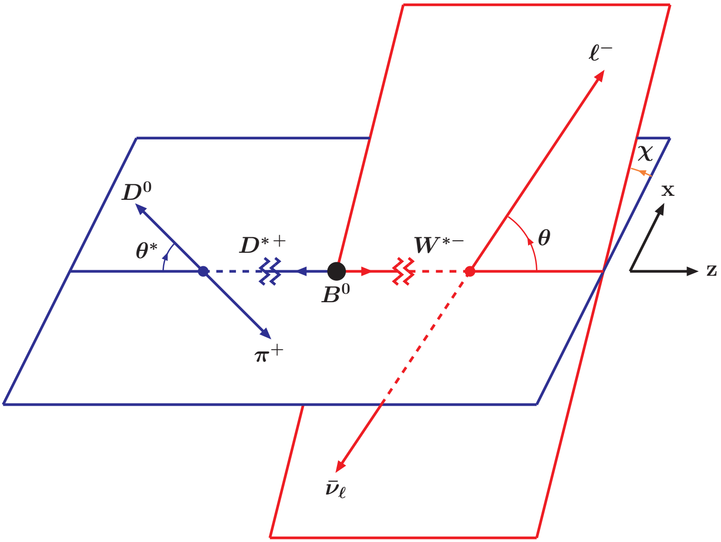
- **Thick black dashed lines are the SM prediction**
- **Gray bands include NP effects corresponding to the 2σ for $V_{L/R}$**
- **Red dotted lines represent the best fit values of the NP couplings**

Ratios of branching fractions $R_D(q^2)$ (left) and $R_{D^*}(q^2)$ (right)

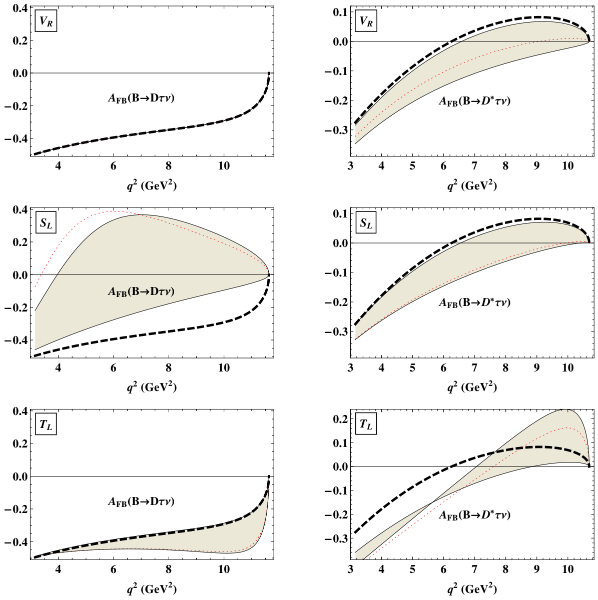


- **Thick black dashed lines are the SM prediction**
- **Gray bands include NP effects corresponding to the 2σ for S_L and 3σ for T_L**
- **Red dotted lines represent the best fit values of the NP couplings**

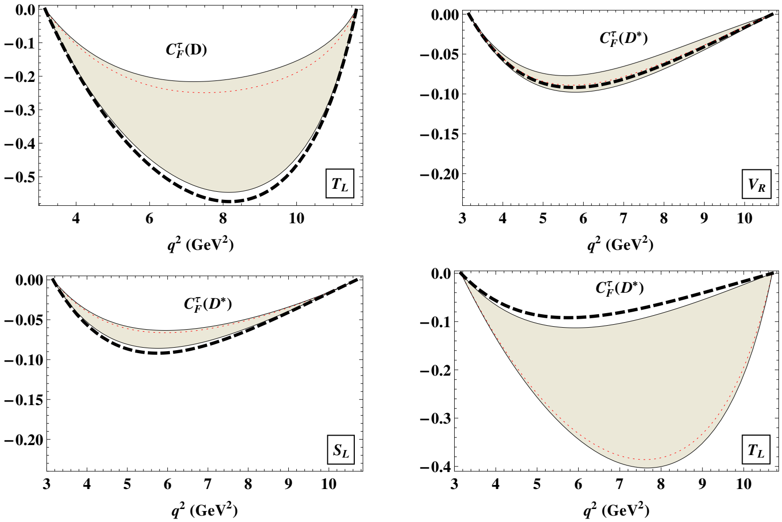
Cascade decay $\bar{B}^0 \to D^{*+}(\to D^0\pi^+)\ell^-\bar{\nu}_\ell$



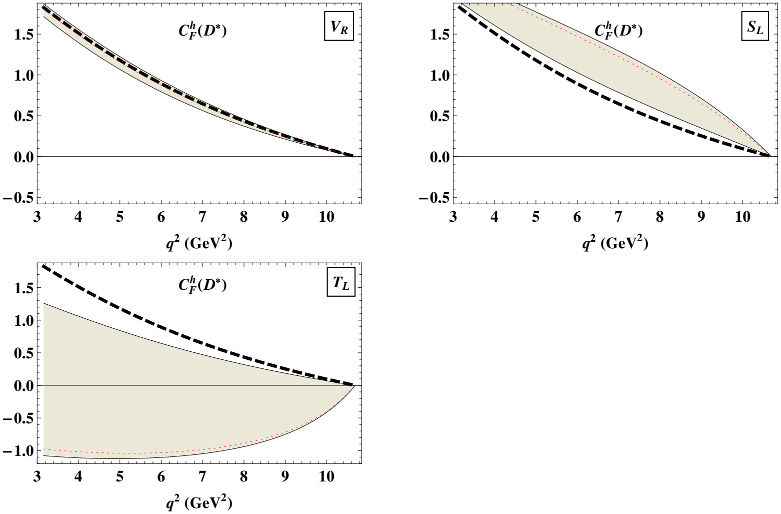
Forward-backward asymmetry $\mathcal{A}_{FB}(q^2)$

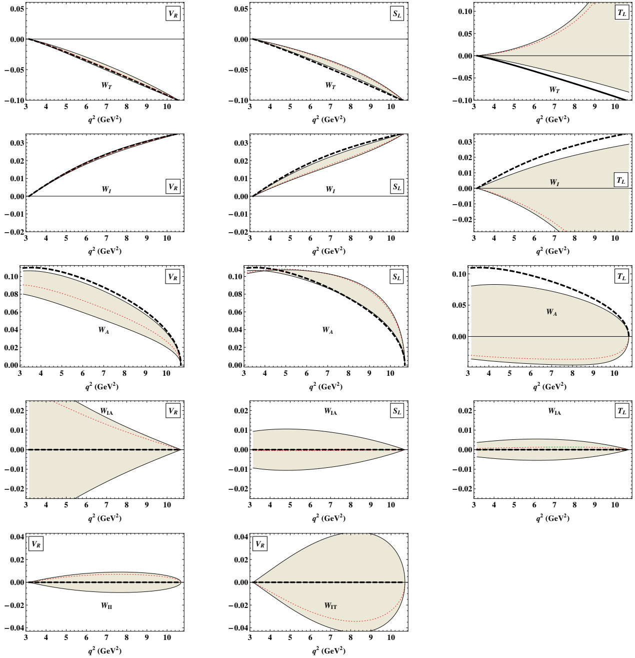


Lepton-side convexity $C_F^\tau(q^2)$



Hadron-side convexity parameter $C_F^h(q^2)$





V_R
S_L
T_L
W_T
W_I
W_A
W_IA
W_II
W_IT
q^2 (GeV^2)

Tau polarization in the decays $\bar{B}^0 \to D^{(*)}\tau^-\bar{\nu}_\tau$

R. Alonso, A. Kobach and J. Martin Camalich, "New physics in the kinematic distributions of $\bar{B} \to D^{(*)}\tau^-(\to \ell^-\bar{\nu}_\ell\nu_\tau)\bar{\nu}_\tau$," Phys. Rev. D 94, no. 9, 094021 (2016)

- **First measurement by Belle:** S. Hirose *et al.* [Belle Collaboration], "Measurement of the τ lepton polarization and $R(D^*)$ in the decay $\bar{B} \to D^*\tau^-\bar{\nu}_\tau$," Phys. Rev. Lett. 118, no. 21, 211801 (2017)

$$P_L^\tau = -0.38 \pm 0.51(\text{stat.})^{+0.21}_{-0.16}(\text{syst.}) \qquad (\text{in } \bar{B}^0 \to D^*\tau^-\bar{\nu}_\tau)$$

- **This pioneering measurement has opened a completely new window on the analysis of the dynamics of semileptonic $B \to D^{(*)}$ transitions.**

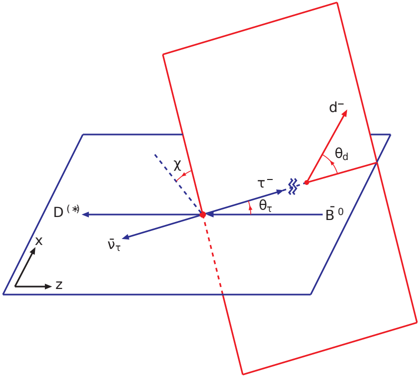
- **The hope is that, with the Belle II super-B factory nearing completion, more precise values of the polarization can be achieved in the future, which would shed more light on the search for possible NP in these decays.**

Analyzing the polarization of the tau through its decays

M. A. Ivanov, J. G. Körner and C. T. Tran, Phys. Rev. D 95, no. 3, 036021 (2017)

Analyzing modes for the τ^- polarization:

$$\tau^- \to \pi^-\nu_\tau \quad (10.83\%), \qquad \tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau \quad (17.41\%),$$
$$\tau^- \to \rho^-\nu_\tau \quad (25.52\%), \qquad \tau^- \to e^-\bar{\nu}_e\nu_\tau \quad (17.83\%).$$



In W rest frame, θ_τ - angle between $\vec{p}_\tau$ and the direction opposite to the direction of the $D^{(*)}$

In τ rest frame, θ_d - angle between d^- and the longitudinal polarization axis, which is chosen to coincide with the direction of the τ in the W rest frame.

χ - azimuthal angle.

The angular decay distribution

In terms of the angles θ_d and χ, the decay distribution is written as:

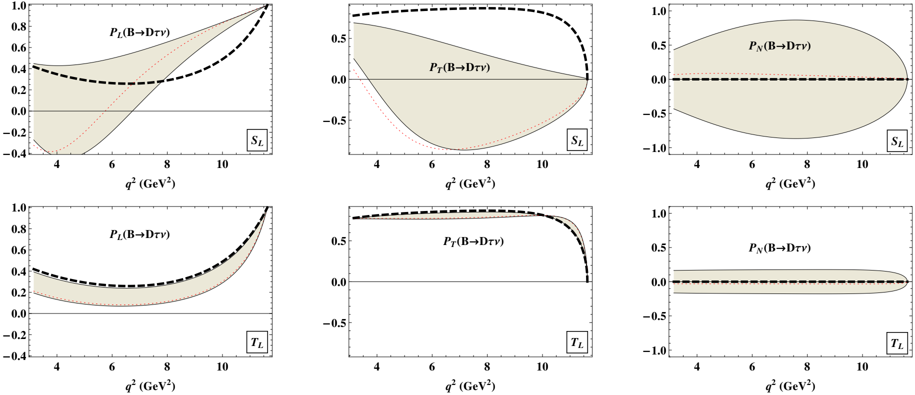
$$\frac{d\Gamma}{dq^2 d\cos\theta_d d\chi/2\pi} = \mathcal{B}_d \frac{d\Gamma}{dq^2}$$

$$\times \quad \frac{1}{2}\left\{1 + A_d \left[P_T(q^2)\sin\theta_d\cos\chi + P_N(q^2)\sin\theta_d\sin\chi + P_L(q^2)\cos\theta_d\right]\right\}$$

One can determine the components of the q^2-dependent polarization vector

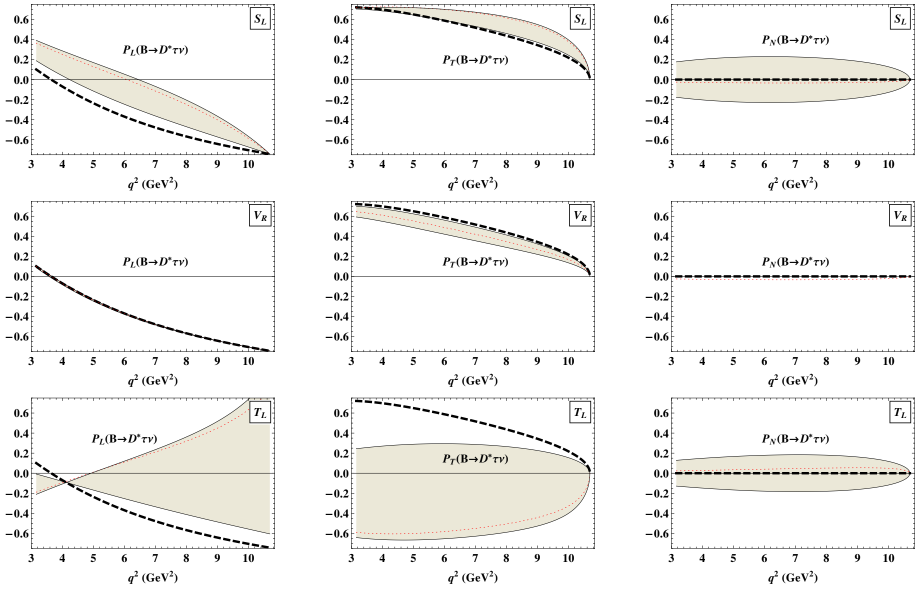
$$\vec{P}(q^2) = (P_T(q^2), P_N(q^2), P_L(q^2)).$$

Longitudinal, transverse, and normal polarization of τ^- in $\bar{B}^0 \to D\tau^-\bar{\nu}_\tau$



- **Thick black dashed lines: SM prediction**
- **Gray bands include NP effects corresponding to the 2σ allowed regions**
- **Red dotted lines represent the best-fit values of the NP couplings**

Longitudinal, transverse, and normal polarization of τ^- in $\bar{B}^0 \to D^* \tau^- \bar{\nu}_\tau$



q^2 averages of the polarization components and the total polarization.

$\bar{B}^0 \to D$

	$< P_L^D >$	$< P_T^D >$	$< P_N^D >$	$< \lvert \vec{P}^D \rvert >$
SM & CCQM	0.33	0.84	0	0.91
S_L	$[0.36, 0.67]$	$[-0.68, 0.33]$	$[-0.76, 0.76]$	$[0.89, 0.96]$
T_L	$[0.13, 0.31]$	$[0.78, 0.83]$	$[-0.17, 0.17]$	$[0.79, 0.90]$

$\bar{B}^0 \to D^*$

	$< P_L^{D^*} >$	$< P_T^{D^*} >$	$< P_N^{D^*} >$	$< \lvert \vec{P}^{D^*} \rvert >$
SM & CCQM	-0.50	0.46	0	0.71
S_L	$[-0.40, -0.14]$	$[0.47, 0.62]$	$[-0.20, 0.20]$	$[0.69, 0.70]$
T_L	$[-0.36, 0.24]$	$[-0.61, 0.26]$	$[-0.17, 0.17]$	$[0.23, 0.69]$
V_R	-0.50	$[0.32, 0.43]$	0	$[0.48, 0.67]$

The predicted intervals for the polarizations in the presence of NP are given in correspondence with the 2σ allowed regions of the NP couplings.

Rare flavor changing neutral current decays

$$B \to K(K^*)\ell^+\ell^-, \qquad B_s \to \phi\ell^+\ell^-, \qquad \Lambda_b \to \Lambda\,\ell^+\ell^-$$

- Effective Hamiltonian describing $b \to s\ell^+\ell^-$ transition

$$\mathcal{H}_{\rm eff} = -\frac{4\,G_F}{\sqrt{2}} V_{tb}V_{ts}^\dagger \sum_{i=1}^{10} \left(C_i \mathcal{O}_i + C_i' \mathcal{O}_i' \right) + h.c.$$

where the primed quantities characterize NP effects.

- A special interest for numerical analysis is the operators

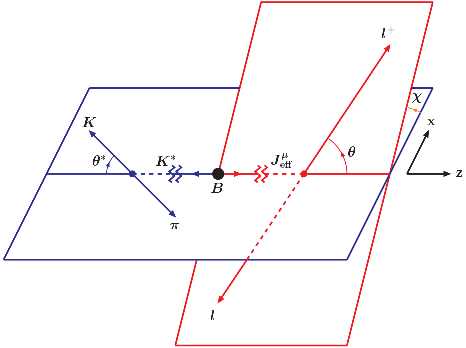
$$\mathcal{O}_7 = \frac{e}{16\pi^2} m_b(\mu)\,(\bar{s}\sigma_{\mu\nu}P_R b)\,\mathcal{F}^{\mu\nu}\,,$$

$$\mathcal{O}_9 = \frac{e^2}{16\pi^2}(\bar{s}\gamma_\mu P_L b)\,(\bar{\ell}\gamma^\mu\ell)\,, \qquad \mathcal{O}_{10} = \frac{e^2}{16\pi^2}(\bar{s}\gamma_\mu P_L b)\,(\bar{\ell}\gamma^\mu\gamma_5\ell)$$

and their primed partners with opposite chiralities.

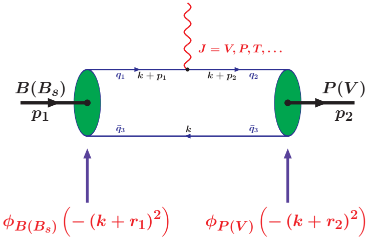
Rare flavor changing neutral current decays

- **If $K(K^*)$, ϕ and Λ are on mass-shell then two-fold distribution $(q^2, \cos\theta)$**
- **If cascade decays $K^* \to K\pi$, $\phi \to K^+K^-$ and $\Lambda \to p\bar{\pi}^-$ then four-fold distribution $(q^2, \cos\theta, \cos\theta^*, \chi)$**

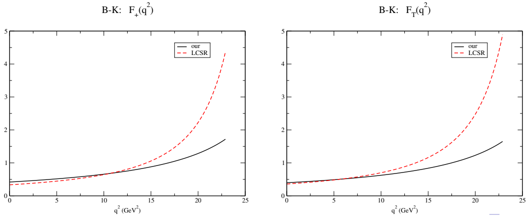


Form factors

S. Dubnička, A. Z. Dubničková, N. Habyl, M. A. Ivanov, A. Liptaj, G. S. Nurbakova, Few Body Syst. 57, 121 (2016)



$$r_i = \frac{m_{q_3}}{m_{q_i}+m_{q_3}}\, p_i$$



Total branching fractions

Mode	Our	Expt.
$B \to K^* \mu^+ \mu^-$	12.7×10^{-7}	$(9.24 \pm 0.93(\mathrm{stat}) \pm 0.67(\mathrm{sys})) \times 10^{-7}$
$B \to K^* \tau^+ \tau^-$	1.35×10^{-7}	
$B \to K^* \gamma$	3.74×10^{-5}	$(4.21 \pm 0.18) \times 10^{-5}$
$B \to K^* \nu \bar{\nu}$	1.36×10^{-5}	
$B \to K \mu^+ \mu^-$	7.18×10^{-7}	$(4.29 \pm 0.07(\mathrm{stat}) \pm 0.21(\mathrm{sys})) \times 10^{-7}$
$B \to K \tau^+ \tau^-$	3.0×10^{-7}	
$B \to K \nu \bar{\nu}$	0.60×10^{-5}	

Lagrangian and 3-quark currents

T. Gutsche, M. A. Ivanov, J. G. Körner, V. E. Lyubovitskij and P. Santorelli, Phys. Rev. D 87, 074031 (2013)

$$\mathcal{L}_{\rm int}^{\Lambda}(x) = g_\Lambda \bar{\Lambda}(x) \cdot J_\Lambda(x) + g_\Lambda \bar{J}_\Lambda(x) \cdot \Lambda(x)$$

$$J_\Lambda(x) = \int dx_1 \int dx_2 \int dx_3 \, F_\Lambda(x; x_1, x_2, x_3) \, J_{3q}^{(\Lambda)}(x_1, x_2, x_3)$$

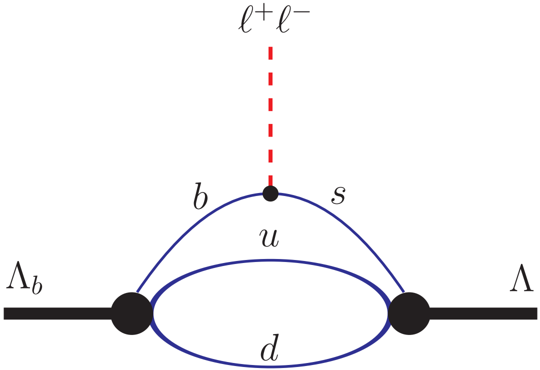
$$J_{3q}^{(\Lambda)}(x_1, x_2, x_3) = Q^{a_1}(x_1) \cdot \epsilon^{a_1 a_2 a_3} \, u^{T\, a_2}(x_2) \, C \, \gamma^5 \, d^{a_3}(x_3)$$

$$Q = s, c, b$$

The vertex function is chosen in the form

$$F_\Lambda(x; x_1, x_2, x_3) = \delta^{(4)}\Big(x - \sum_{i=1}^{3} w_i x_i\Big) \, \Phi_\Lambda\Big(\sum_{i<j} (x_i - x_j)^2\Big) \qquad w_i = \frac{m_i}{m_1 + m_2 + m_3}$$

Two-loop diagram



The fit of the size parameters

Branching ratios of semileptonic decays of heavy baryons in %.

Mode	Our results	Data
$\Lambda_c \to \Lambda e^+ \nu_e$	2.0	2.1 ± 0.6
$\Lambda_c \to \Lambda \mu^+ \nu_\mu$	2.0	2.0 ± 0.7
$\Lambda_b \to \Lambda_c e^- \bar{\nu}_e$	6.6	$6.5^{+3.2}_{-2.5}$
$\Lambda_b \to \Lambda_c \mu^- \bar{\nu}_\mu$	6.6	
$\Lambda_b \to \Lambda_c \tau^- \bar{\nu}_\tau$	1.8	

Asymmetry parameter α in the semileptonic decays of heavy baryons.

Mode	Our results	Data
$\Lambda_c \to \Lambda e^+ \nu_e$	0.828	0.86 ± 0.04
$\Lambda_c \to \Lambda \mu^+ \nu_\mu$	0.825	
$\Lambda_b \to \Lambda_c e^- \bar{\nu}_e$	0.831	
$\Lambda_b \to \Lambda_c \mu^- \bar{\nu}_\mu$	0.831	
$\Lambda_b \to \Lambda_c \tau^- \bar{\nu}_\tau$	0.731	

Branching fractions of decays $\Lambda_b \to \Lambda + \ell^+\ell^-$ and $\Lambda_b \to \Lambda + \gamma$

Our results:

$$\mathcal{B}(\Lambda_b \to \Lambda\mu^+\mu^-) = 1.0 \cdot 10^{-6}$$

T. Gutsche, M. A. Ivanov, J. G. Körner, V. E. Lyubovitskij and P. Santorelli, Phys. Rev. D 87 074031 (2013)

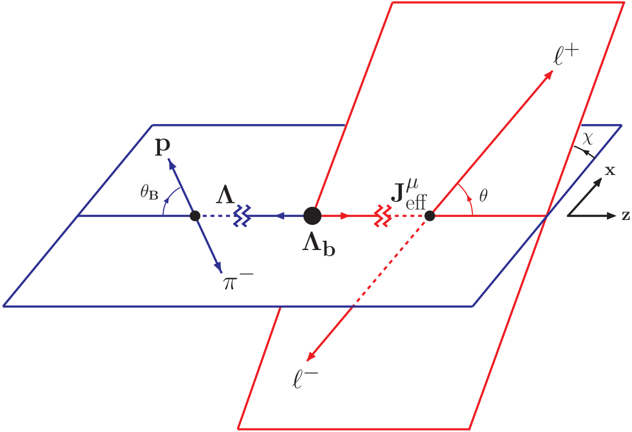
to be compared with the recent LHCb data:

$$\mathcal{B}(\Lambda_b \to \Lambda\mu^+\mu^-) = (0.96 \pm 0.16(\text{stat}) \pm 0.13(\text{syst}) \pm 0.21(\text{norm})) \cdot 10^{-6}$$

RAaij *et al.* [LHCb Collaboration], arXiv:1306.2577 [hep-ex].

$\mathcal{B}(\Lambda_b \to \Lambda\gamma) = 0.4 \cdot 10^{-5}$ (experimental upper bound $< 130 \cdot 10^{-5}$)

The angular decay distribution for the cascade decay $\Lambda_b \to \Lambda(\to p\pi^-)\ell^+\ell^-$



Asymmetries A_{FB}^{ℓ} and A_{FB}^{h}

Mode	A_{FB}^{ℓ}	A_{FB}^{h}
$\Lambda_b \to \Lambda e^+ e^-$	3.2×10^{-10}	-0.321
$\Lambda_b \to \Lambda \mu^+ \mu^-$	1.7×10^{-4}	-0.300
$\Lambda_b \to \Lambda \tau^+ \tau^-$	5.9×10^{-4}	-0.265

Semileptonic and nonleptonic Λ_b-decays

- **Polarization effects in the cascade decay**

$$\mathbf{\Lambda_b \to \Lambda(\to p\pi^-) + J/\psi(\to \ell^+\ell^-)}$$

T. Gutsche, M. A. Ivanov, J. G. Körner, V. E. Lyubovitskij, P. Santorelli, Phys. Rev. D 88 114018 (2013)

- **Heavy-to-light semileptonic decays of Λ_b and Λ_c baryons**

$$\mathbf{\Lambda_b \to p\ell^-\bar{\nu} \text{ and } \Lambda_c \to n\ell^+\bar{\nu}}$$

T. Gutsche, M. A. Ivanov, J. G. Körner, V. E. Lyubovitskij,P. Santorelli, Phys. Rev. D 90 114033 (2014)

- **Semileptonic decays**

$$\mathbf{\Lambda_b \to \Lambda_c\tau^-\bar{\nu}_\tau \text{ and } \Lambda_c \to \Lambda\ell^+\bar{\nu}}$$

T. Gutsche, M. A. Ivanov, J. G. Körner, V. E. Lyubovitskij, P. Santorelli and N. Habyl, Phys. Rev. D 91 074001 (2015) Erratum: [Phys. Rev. D 91 119907 (2015)]

T. Gutsche, M. A. Ivanov, J. G. Körner, V. E. Lyubovitskij, P. Santorelli, Phys. Rev. D 93 034008 (2016)

Summary

- **The observed enhancements of the tauonic mode in the (semi)leptonic B-meson decay may indicate a violation of lepton universality.**

- **At present, the measurements are limited by the available experimental uncertainties**

- **In the near future, LHCb will measure $\bar{B} \to D\tau^- \bar{\nu}_\tau$ decay and improve results for $\bar{B} \to D^* \tau^- \bar{\nu}_\tau$.**

- **In addition, searches for lepton universality violation in semileptonic decays of Λ_b-baryons are being planned.**

Summary

- **At KEK in Japan, e^+e^- collider and the Belle detector are also being upgraded. It will allow more precise measurements the τ-polarization in $B \to D^* \tau \nu_\tau$ decays.**
- **The future data will show whether the obtained results are an indication of beyond-the-SM physics or the result of larger-than-expected statistical or systematic deviations.**
- **A confirmation of new physics contributions in these decays would change our understanding of matter and trigger an intense program of experimental and theoretical research.**