Probing New Physics with Heavy Hadron decays

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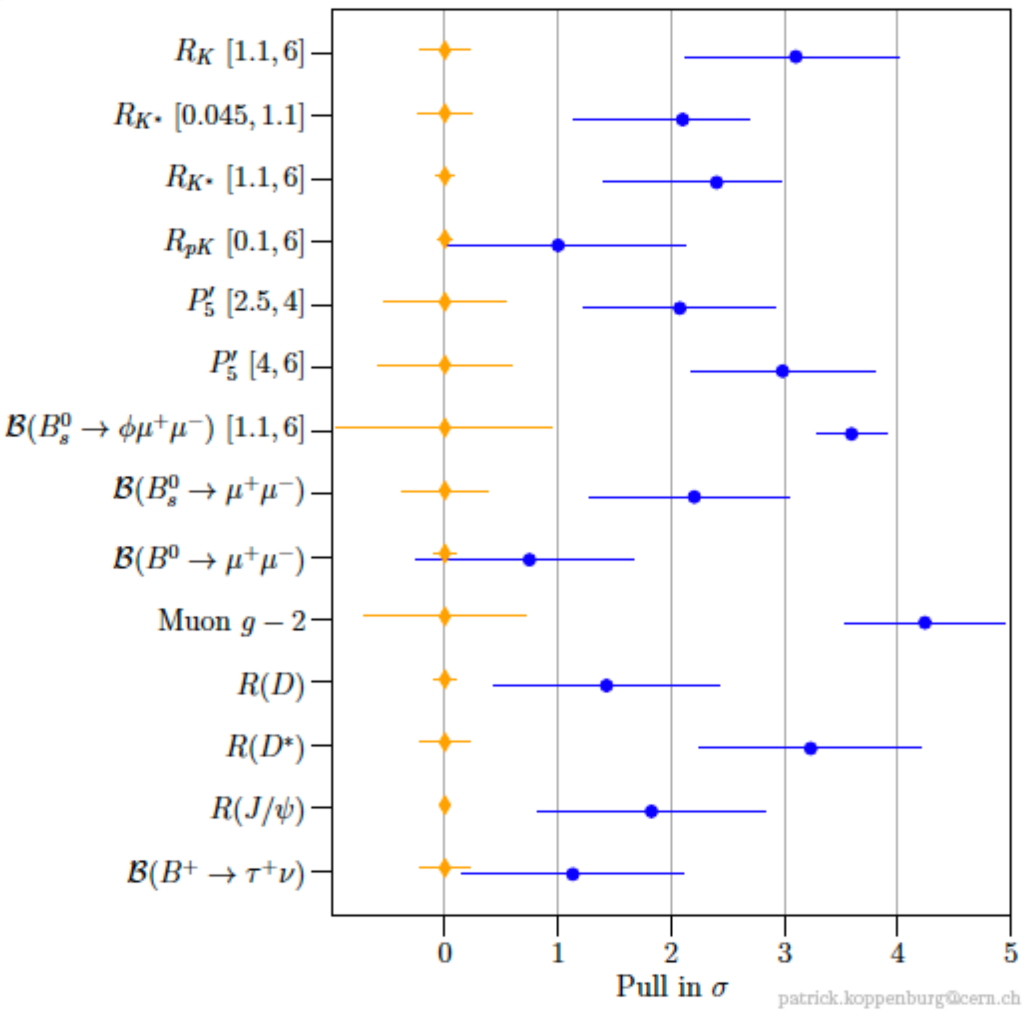
based on:
Inclusive semileptonic Λ_b decays in the Standard Model and beyond
P. Colangelo, F. Loparco, FDF
JHEP 11 (2020) 032 , arXiv:2006.13759

New & Old Anomalies



New & Old Anomalies

1) SM allowed processes: deviations from expectations → NP

- tree level decays ($R(D^{(*)})$ & co.)
- loop (rare) decays ($R(K^{(*)})$, P'_5, …)
- puzzling quantities (V_{cb}, V_{ub}, ε'/ε, $(g-2)_\mu$…).

2) SM forbidden processes: observation → NP

- LFV decays $\tau \to 3\mu$, $\mu \to e\,\gamma$ …

- many hints of LFU violation ⇢ relation between 1) and 2) expected

- Common origin of the anomalies?
  ex: Problems with V_{cb} and V_{ub} determinations might be correlated
  with observed anomalies in tree level modes

P. Colangelo, FDF
PRD 95 (17) 011701

Systematic extension of the SM

Weinberg Opertor: ν oscillations

$$\boxed{\mathcal{L}_{SMEFT} = \mathcal{L}_{SM} + \frac{1}{\Lambda_{(5)}}\mathcal{O}^{(D=5)} + \sum_i \frac{1}{\Lambda_i^2}\mathcal{O}_i^{(D=6)} + \dots}$$

$$\overbrace{\underbrace{\mathcal{L}^{kin} + \mathcal{L}^{gauge} + \mathcal{L}^{Higgs}}_{\text{Accidental symmetries}} + \underbrace{\mathcal{L}^{Yukawa}}}$$

NP

Accidental symmetries

- Violates accidental symmetries
- Source of (SM) CP violation
- Fermion mass terms

Semileptonic b decays

Exclusive b → c,u modes

- Identifications of suitable observables
- Issue of FF uncertainties
- b → c unsolved debate: role of the parametrization: BGL vs CLN in heavy-to-heavy FF
  Proposed to reconcile inclusive vs exclusive V_{cb} determinations

🤔 what about V_{ub}?

Inclusive b → c,u modes (exploit HQE)

- Identifications of suitable observables
- Higher orders in $1/m_Q$ and α_s
- role of shape function

Common starting point (U=c,u)

$$
\begin{aligned}
H_{\rm eff}^{b\to U\ell\nu} = \frac{G_F}{\sqrt{2}} V_{Ub} \Big[& \left(1+\epsilon_V^\ell\right) \left(\bar{U}\gamma_\mu(1-\gamma_5)b\right) \left(\bar{\ell}\gamma^\mu(1-\gamma_5)\nu_\ell\right) \\
& + \epsilon_S^\ell \left(\bar{U}b\right) \left(\bar{\ell}(1-\gamma_5)\nu_\ell\right) + \epsilon_P^\ell \left(\bar{U}\gamma_5 b\right) \left(\bar{\ell}(1-\gamma_5)\nu_\ell\right) \\
& + \epsilon_T^\ell \left(\bar{U}\sigma_{\mu\nu}(1-\gamma_5)b\right) \left(\bar{\ell}\sigma^{\mu\nu}(1-\gamma_5)\nu_\ell\right) \\
& + \epsilon_R^\ell \left(\bar{U}\gamma_\mu(1+\gamma_5)b\right) \left(\bar{\ell}\gamma^\mu(1-\gamma_5)\nu_\ell\right) \Big] + h.c. \ \ .
\end{aligned}
$$

Extends the SM effective Hamiltonian

Common starting point (U=c,u)

SM

$$
\begin{aligned}
H_{\text{eff}}^{b\to U\ell\nu} = \frac{G_F}{\sqrt{2}} V_{Ub} \Big[& (1+\epsilon_V^\ell)\,(\bar{U}\gamma_\mu(1-\gamma_5)b)\,(\bar{\ell}\gamma^\mu(1-\gamma_5)\nu_\ell) \\
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& + \epsilon_R^\ell\,(\bar{U}\gamma_\mu(1+\gamma_5)b)\,(\bar{\ell}\gamma^\mu(1-\gamma_5)\nu_\ell) \Big] + h.c. \;.
\end{aligned}
$$

complex
LF-dependent couplings

Extends the SM effective Hamiltonian

b-baryon decays

- Investigate correlations to similar processes in meson (B_s, B_c) decays and in b-baryon (Λ_b, Ξ_b, Ω_b) decays

- inclusive widths : use - Optical theorem
  - Heavy Quark expansion (HQE)

Pioneering works: J. Chay, H. Georgi and B. Grinstein, PLB 247 (1990) 399
I.I.Y. Bigi, M.A. Shifman, N.G. Uraltsev and A.I. Vainshtein, PRL 71 (1993) 496

Inclusive decay width

$$H_{\rm eff}^{b\to U\ell\nu} = \frac{G_F}{\sqrt{2}} V_{Ub} \sum_{i=1}^{5} C_i^{\ell}\, J_M^{(i)}\, L^{(i)M} + h.c.$$

Hadronic currents

Leptonic currents

$$C_1^{\ell} = (1+\epsilon_V^{\ell})$$

$$C_{2,3,4,5}^{\ell} = \epsilon_{S,P,T,R}^{\ell}$$

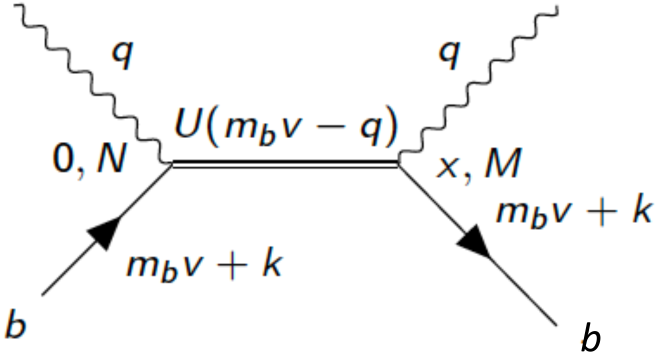
SM: $\epsilon_{V,S,P,T,R}^{\ell} = 0$

$$J_\mu^{(1)} = \overline{U}\gamma_\mu(1-\gamma_5)b$$

$$L^{\mu(1)} = \bar{\ell}\gamma_\mu(1-\gamma_5)\nu_\ell$$

$$d\Gamma = d\Sigma \frac{G_F^2|V_{Ub}|^2}{4m_H} \sum_{i,j} C_i^* C_j \underbrace{(W^{ij})_{MN}}_{\text{Hadronic tensor}} \underbrace{(L^{ij})^{MN}}_{\text{Leptonic tensor}}$$

$$(W^{ij})_{MN} = \frac{1}{\pi}{\rm Im}(T^{ij})_{MN}$$



$$(T^{ij})_{MN} = i\int d^4x\, e^{i(m_b v - q)\cdot x}\langle H_b(v,s)|T[\hat{J}_M^{(i)\dagger}(x)\,\hat{J}_N^{(j)}(0)]|H_b(v,s)\rangle$$

$$= \langle H_b(v,s)|\bar{b}_v(0)\Gamma_M^{(i)\dagger} S_U(p_X)\Gamma_N^{(j)} b_v(0)|H_b(v,s)\rangle$$

Intermediate U quark propagator

Inclusive decay width

Expansion:

$$S_U(p_X) = S_U^{(0)} - S_U^{(0)}(i\not{D})S_U^{(0)} + S_U^{(0)}(i\not{D})S_U^{(0)}(i\not{D})S_U^{(0)} + \dots$$

$$\frac{1}{m_b\not{v} - \not{q} - m_U}$$

$$\boxed{\begin{aligned}\frac{1}{\pi}\mathrm{Im}(T^{ij})_{MN} = &\frac{1}{\pi}\mathrm{Im}\frac{1}{\Delta_0}\langle H_b(v,s)|\bar{b}_v[\Gamma_M^{(i)\dagger}\mathcal{P}\Gamma_N^{(j)}]b_v|H_b(v,s)\rangle \\ &- \frac{1}{\pi}\mathrm{Im}\frac{1}{\Delta_0^2}\langle H_b(v,s)|\bar{b}_v[\Gamma_M^{(i)\dagger}\mathcal{P}\gamma^{\mu_1}\mathcal{P}\Gamma_N^{(j)}](iD_{\mu_1})b_v|H_b(v,s)\rangle \\ &+ \frac{1}{\pi}\mathrm{Im}\frac{1}{\Delta_0^3}\langle H_b(v,s)|\bar{b}_v[\Gamma_M^{(i)\dagger}\mathcal{P}\gamma^{\mu_1}\mathcal{P}\gamma^{\mu_2}\mathcal{P}\Gamma_N^{(j)}](iD_{\mu_1})(iD_{\mu_2})b_v|H_b(v,s)\rangle \\ &- \frac{1}{\pi}\mathrm{Im}\frac{1}{\Delta_0^4}\langle H_b(v,s)|\bar{b}_v[\Gamma_M^{(i)\dagger}\mathcal{P}\gamma^{\mu_1}\mathcal{P}\gamma^{\mu_2}\mathcal{P}\gamma^{\mu_3}\mathcal{P}\Gamma_N^{(j)}](iD_{\mu_1})(iD_{\mu_2})(iD_{\mu_3})b_v|H_b(v,s)\rangle\,.\end{aligned}}$$

$$\left\{\begin{aligned}\Delta_0 &= p_U^2 - m_U^2 \\ p_U &= m_b v - q\end{aligned}\right.$$

HQE

Requires hadronic matrix elements with increasing number of derivatives:

$$\boxed{\mathcal{M}_{\mu_1\dots\mu_n} = \langle H_b(v,s)|(\bar{b}_v)_a(iD_{\mu_1})\dots(iD_{\mu_n})(b_v)_b|H_b(v,s)\rangle}$$

can be expressed in terms of non perturbative parameters

Inclusive decay width

$$\mathcal{O}\left(\frac{1}{m_b^n}\right)\ldots\begin{cases}\mathcal{O}\left(\frac{1}{m_b^3}\right) & \begin{cases}\mathcal{O}\left(\frac{1}{m_b^2}\right) & \begin{cases}-2\,M_H\,\hat{\mu}_\pi^2 = \langle H_b|\bar{b}_v\; iD^\mu\; iD_\mu\; b_v|H_b\rangle \\ 2\,M_H\,\hat{\mu}_G^2 = \langle H_b|\bar{b}_v\;(-i\sigma_{\mu\nu})\; iD^\mu\; iD^\nu\; b_v|H_b\rangle\end{cases} \\ 2\,M_H\,\hat{\rho}_D^3 = \langle H_b|\bar{b}_v\; iD^\mu\;(iv\cdot D)\; iD_\mu\; b_v|H_b\rangle \\ 2\,M_H\,\hat{\rho}_{LS}^3 = \langle H_b|\bar{b}_v\;(-i\sigma_{\mu\nu})\; iD^\mu\;(iv\cdot D)\; iD^\nu\; b_v|H_b\rangle\end{cases} \\ \ldots\end{cases}$$

Inclusive decay width

$$\mathcal{O}\left(\frac{1}{m_b^n}\right) \dots \begin{cases} \mathcal{O}\left(\frac{1}{m_b^3}\right) \begin{cases} \mathcal{O}\left(\frac{1}{m_b^2}\right) \begin{cases} -2\, M_H\, \hat{\mu}_\pi^2 = \langle H_b | \bar{b}_v\, iD^\mu\, iD_\mu\, b_v | H_b \rangle \\ 2\, M_H\, \hat{\mu}_G^2 = \langle H_b | \bar{b}_v\, (-i\sigma_{\mu\nu})\, iD^\mu\, iD^\nu\, b_v | H_b \rangle \end{cases} \\ 2\, M_H\, \hat{\rho}_D^3 = \langle H_b | \bar{b}_v\, iD^\mu\, (iv \cdot D)\, iD_\mu\, b_v | H_b \rangle \\ 2\, M_H\, \hat{\rho}_{LS}^3 = \langle H_b | \bar{b}_v\, (-i\sigma_{\mu\nu})\, iD^\mu\, (iv \cdot D)\, iD^\nu\, b_v | H_b \rangle \end{cases} \\ \dots \end{cases}$$

$\hat{\mu}_\pi^2$ matrix element of the kinetic energy operator

is different for different hadrons (i.e. B and Λ_b)

$$\boxed{\mu_\pi^2(B) - \mu_\pi^2(\Lambda_b) = \frac{2 m_b m_c}{m_b - m_c} \left[(m_{\Lambda_b} - m_{\Lambda_c}) - (\overline{m}_B - \overline{m}_D) \right] \left(1 + \mathcal{O}(1/m_{b,c}^2)\right)}$$

$$\boxed{\hat{\mu}_\pi^2(\Lambda_b) = (0.50 \pm 0.1)\, \mathrm{GeV}^2}$$

Inclusive decay width

$$\mathcal{O}\left(\frac{1}{m_b^n}\right)\ldots\begin{cases}\mathcal{O}\left(\frac{1}{m_b^3}\right)\begin{cases}\mathcal{O}\left(\frac{1}{m_b^2}\right)\begin{cases}-2\,M_H\,\hat{\mu}_\pi^2 = \langle H_b|\bar{b}_v\,iD^\mu\,iD_\mu\,b_v|H_b\rangle\\ 2\,M_H\,\hat{\mu}_G^2 = \langle H_b|\bar{b}_v\,(-i\sigma_{\mu\nu})\,iD^\mu\,iD^\nu\,b_v|H_b\rangle\end{cases}\\ 2\,M_H\,\hat{\rho}_D^3 = \langle H_b|\bar{b}_v\,iD^\mu\,(iv\cdot D)\,iD_\mu\,b_v|H_b\rangle\\ 2\,M_H\,\hat{\rho}_{LS}^3 = \langle H_b|\bar{b}_v\,(-i\sigma_{\mu\nu})\,iD^\mu\,(iv\cdot D)\,iD^\nu\,b_v|H_b\rangle\end{cases}\\ \ldots\end{cases}$$

$\hat{\mu}_G^2$ matrix element of the chromomagnetic operator

depends on the spin of the hadron and can be fixed from data (mass splittings)

$$\boxed{\hat{\mu}_G^2(\Lambda_b) = 0}$$

Inclusive decay width

$$\mathcal{O}\left(\frac{1}{m_b^n}\right)\dots\begin{cases}\mathcal{O}\left(\frac{1}{m_b^3}\right)\begin{cases}\mathcal{O}\left(\frac{1}{m_b^2}\right)\begin{cases}-2\,M_H\,\hat{\mu}_\pi^2 = \langle H_b|\bar{b}_v\, iD^\mu\, iD_\mu\, b_v|H_b\rangle\\ 2\,M_H\,\hat{\mu}_G^2 = \langle H_b|\bar{b}_v\,(-i\sigma_{\mu\nu})\, iD^\mu\, iD^\nu\, b_v|H_b\rangle\end{cases}\\ 2\,M_H\,\hat{\rho}_D^3 = \langle H_b|\bar{b}_v\, iD^\mu\,(iv\cdot D)\, iD_\mu\, b_v|H_b\rangle\\ 2\,M_H\,\hat{\rho}_{LS}^3 = \langle H_b|\bar{b}_v\,(-i\sigma_{\mu\nu})\, iD^\mu\,(iv\cdot D)\, iD^\nu\, b_v|H_b\rangle\end{cases}\\ \dots\end{cases}$$

$\hat{\rho}_D^3$ Darwin term approx: $\boxed{\rho_D^3(\Lambda_b)\simeq\rho_D^3(B)}$ $\boxed{\rho_D^3(\Lambda_b) = (0.17\pm 0.08)\,\mathrm{GeV}^3}$

$\hat{\rho}_{LS}^3$ spin-orbit term $\boxed{\hat{\rho}_{LS}^3(\Lambda_b) = 0}$

Results

$$\mathcal{M}_{\mu_1\ldots\mu_n} = \langle H_b(v,s)|(\bar{b}_v)_a(iD_{\mu_1})\ldots(iD_{\mu_n})(b_v)_b|H_b(v,s)\rangle$$

General parametrization including **dependence on the spin** up to $O(m_b^{-3})$ not known before
Method derived for B mesons in B.M. Dassinger, T. Mannel and S. Turczyk, JHEP 03 (2007) 087

New terms depending on the spin appear for a **polarized baryon**

- Analytic results
- Main outcome of our study
- Applies to all spin ½ baryons

Results at $O(m_b^{-2})$: A.V. Manohar and M.B. Wise, PRD 49 (1994) 1310
S. Balk, J.G. Korner and D. Pirjol, EPJC 1 (1998) 221

Results

$$\mathcal{M}^{\rho\sigma\lambda} = M_H \left[\left(\frac{\hat\rho_D^3}{3} \Pi^{\rho\lambda} v^\sigma P_+ + \frac{\hat\rho_{LS}^3}{6} v^\sigma \, i\,\epsilon^{\rho\lambda\alpha\beta} v_\alpha S_\beta \right) - \left(\frac{\hat\rho_D^3}{3} \Pi^{\rho\lambda} v^\sigma s^\mu S_\mu - \frac{\hat\rho_{LS}^3}{2} v^\sigma \, i\,\epsilon^{\rho\lambda\alpha\beta} v_\alpha s_\beta P_+ \right) \right]$$

$$\begin{aligned}
\mathcal{M}^{\rho\sigma} = M_H \Bigg[\Bigg(& \frac{\hat\mu_\pi^2}{3} \Pi^{\rho\sigma} P_+ + \frac{\hat\mu_G^2}{6} \, i\,\epsilon^{\rho\sigma\alpha\beta} v_\alpha S_\beta + \\
& + \frac{\hat\rho_D^3 + \hat\rho_{LS}^3}{24 m_b} \Big(4 \left(i\,\epsilon^{\rho\sigma\alpha\beta} v_\alpha S_\beta - v^\rho v^\sigma \not{v} \right) + \\
& \qquad + v^\rho \left(2\gamma^\sigma + \not{v}\gamma^\sigma - \gamma^\sigma \not{v} \right) + v^\sigma \left(2\gamma^\rho + \not{v}\gamma^\rho - \gamma^\rho \not{v} \right) \Big) \Bigg) + \\
& + \Bigg(- \frac{\hat\mu_\pi^2}{3} \Pi^{\rho\sigma} P_+ \not{s}\gamma_5 + \frac{\hat\mu_G^2}{2} \, i\,\epsilon^{\rho\sigma\alpha\beta} v_\alpha s_\beta P_+ + \\
& \quad + \frac{\hat\rho_D^3}{12 m_b} \Big(6\, i\,\epsilon^{\rho\sigma\alpha\beta} v_\alpha s_\beta + i \left(v^\rho \epsilon^{\sigma\mu\alpha\beta} - v^\sigma \epsilon^{\rho\mu\alpha\beta} \right) v_\alpha s_\beta \gamma_\mu + \\
& \qquad + s^\rho v^\sigma \not{v}\gamma_5 + v^\rho s^\sigma \left(2\gamma_5 + \not{v}\gamma_5 \right) + \left(2 v^\rho v^\sigma \not{v} - v^\rho \gamma^\sigma - v^\sigma \gamma^\rho \right) \not{s}\gamma_5 \Big) + \\
& \quad + \frac{\hat\rho_{LS}^3}{8 m_b} \Big(4\, i\,\epsilon^{\rho\sigma\alpha\beta} v_\alpha s_\beta + i \left(v^\rho \epsilon^{\sigma\mu\alpha\beta} - v^\sigma \epsilon^{\rho\mu\alpha\beta} \right) v_\alpha s_\beta \gamma_\mu + \\
& \qquad + \left(s^\rho v^\sigma + v^\rho s^\sigma \right) \gamma_5 + \left(2 v^\rho v^\sigma \not{v} - v^\rho \gamma^\sigma - v^\sigma \gamma^\rho \right) \not{s}\gamma_5 \Big) \Bigg) \Bigg]
\end{aligned}$$

P. Colangelo, F. Loparco, FDF
JHEP 11 (2020) 032

Results

$$\mathcal{M}^\rho = M_H \Bigg[\Bigg(\frac{\hat\mu_\pi^2-\hat\mu_G^2}{12m_b}\left(v^\rho\,(3+5\,\slashed{v})-2\,\gamma^\rho\right)-\frac{\hat\rho_D^3+\hat\rho_{LS}^3}{12m_b^2}\left(4\,v^\rho\,\slashed{v}-\gamma^\rho\right)\Bigg)+$$

$$+\Bigg(-\frac{\hat\mu_\pi^2}{12m_b}\left(\left(v^\rho\,(3+5\,\slashed{v})-2\,\gamma^\rho\right)\slashed{s}\,\gamma_5+4\,s^\rho\,\mathrm{P}_+\,\gamma_5\right)+$$

$$+\frac{\hat\mu_G^2}{4m_b}\left(\left(v^\rho\,(1+2\,\slashed{v})-\gamma^\rho\right)\slashed{s}\,\gamma_5+s^\rho\,\gamma_5\right)+$$

$$+\frac{\hat\rho_D^3}{12m_b^2}\left(\left(v^\rho\,(1+4\,\slashed{v})-2\,\gamma^\rho\right)\slashed{s}\,\gamma_5+s^\rho\,(2-\slashed{v})\,\gamma_5\right)+$$

$$+\frac{\hat\rho_{LS}^3}{8m_b^2}\left(\left(3\,v^\rho\,\slashed{v}-\gamma^\rho\right)\slashed{s}\,\gamma_5+s^\rho\,\gamma_5\right)\Bigg)\Bigg]$$

$$\mathcal{M} = M_H\left[\left(\mathrm{P}_+-\frac{\hat\mu_\pi^2-\hat\mu_G^2}{4m_b^2}\right)+\left(\mathrm{P}_++\frac{\hat\mu_\pi^2}{24m_b^2}(7+5\,\slashed{v})-\frac{\hat\mu_G^2}{8m_b^2}(3+\slashed{v})-\frac{\hat\rho_D^3}{6m_b^3}\,\mathrm{P}_-\right)\slashed{s}\,\gamma_5\right]$$

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Fully differential decay width

$$\frac{d^4\Gamma}{dE_\ell\, dq^2\, dq_0\, d\cos\theta_P}$$

- E_ℓ: lepton energy, with $p_\ell = (E_\ell, \boldsymbol{p}_\ell)$;
- q^2: dilepton invariant mass, with $q = (q_0, \boldsymbol{q})$;
- θ_P: angle between the hadron spin $\boldsymbol{s}$ and the lepton 3-momentum $\boldsymbol{p}_\ell$, i.e. $\cos\theta_P = \frac{\boldsymbol{s}\cdot\boldsymbol{p}_\ell}{|\boldsymbol{s}||\boldsymbol{p}_\ell|}$.

Computed with the inclusion of all NP operators

$$\Gamma(H_b \to X_U \ell^- \bar{\nu}_\ell) = \Gamma_0 \sum_{i,j} g_i^* g_j \left[C_0^{(i,j)} + \frac{\hat{\mu}_\pi^2}{m_b^2} C_{\hat{\mu}_\pi^2}^{(i,j)} + \frac{\hat{\mu}_G^2}{m_b^2} C_{\hat{\mu}_G^2}^{(i,j)} + \frac{\hat{\rho}_D^3}{m_b^3} C_{\hat{\rho}_D^3}^{(i,j)} + \frac{\hat{\rho}_{LS}^3}{m_b^3} C_{\hat{\rho}_{LS}^3}^{(i,j)} \right]$$

$$\Gamma_0 = \frac{G_F^2 |V_{Ub}|^2 m_b^5}{192\pi^3}$$

Include the effects of NP through the ε parameters

Complete expression at $O(1/m_b^3)$ in SM, including all NP operators and for non vanishing lepton mass
Rather lengthy P. Colangelo, F. Loparco, FDF JHEP 11 (2020) 032 , arXiv:2006.13759

Numerical Results

Identification of observables sensitive to Λ_b polarization and to BSM effects
(Longitudinal polarization expected for Λ_b resulting from b quark produced in top or Z^0 decays)

P. Colangelo, F. Loparco, FDF
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$$\boxed{\frac{d\Gamma(\Lambda_b \to X_U \ell \bar\nu_\ell)}{d\cos\theta_P} = A_\ell^U + B_\ell^U \cos\theta_P}$$

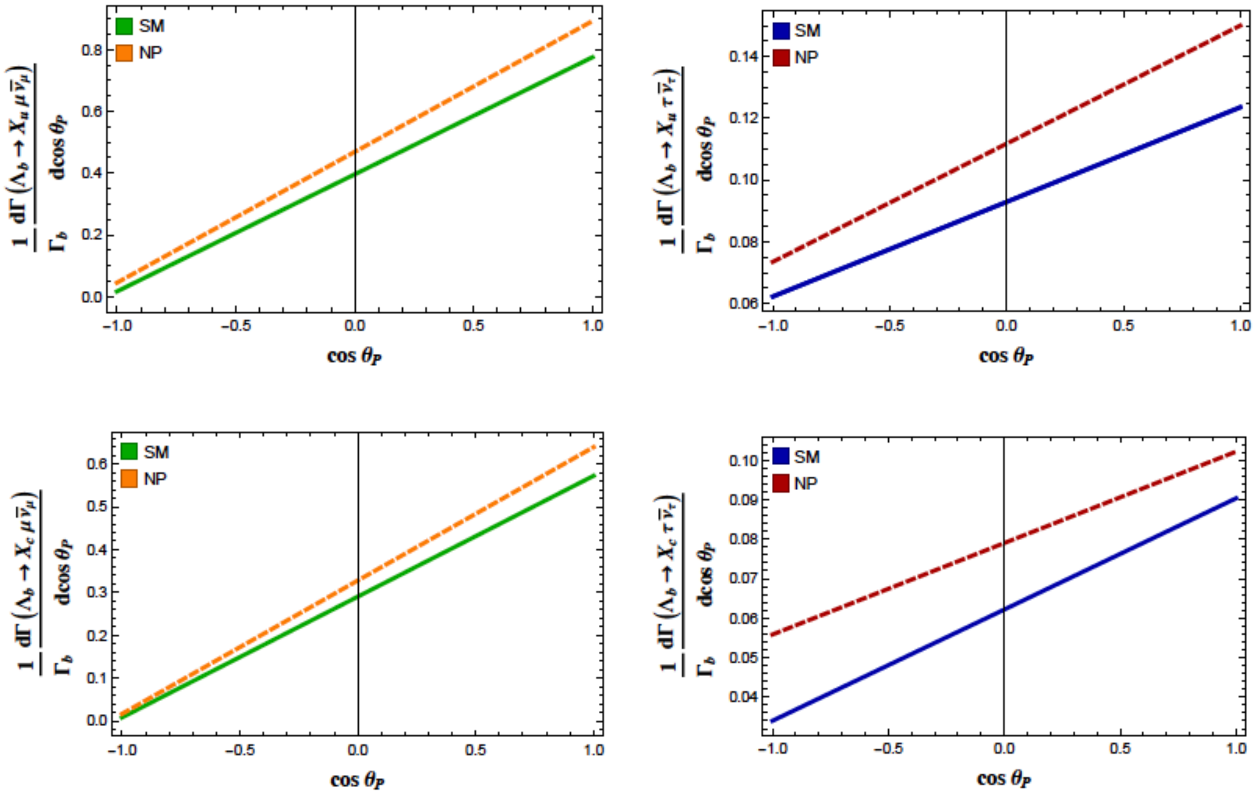
angle between
ℓ^- direction and Λ_b spin

$$\boxed{R_{\Lambda_b}(X_U) = \frac{A_\tau^U}{A_\mu^U}}$$

analogous to R(D$^{(*)}$)
does not require
considering
polarization

$$\boxed{R_S^U = \frac{B_\tau^U}{B_\mu^U}}$$

slope ratios for $\ell=\tau$ and $\ell=\mu$



NP: benchmark points
b ->u P. Colangelo, F. Loparco, FDF, PRD 100 (19) 075037

b ->c P. Colangelo, FDF, JHEP 06 (18) 082 (BP1)
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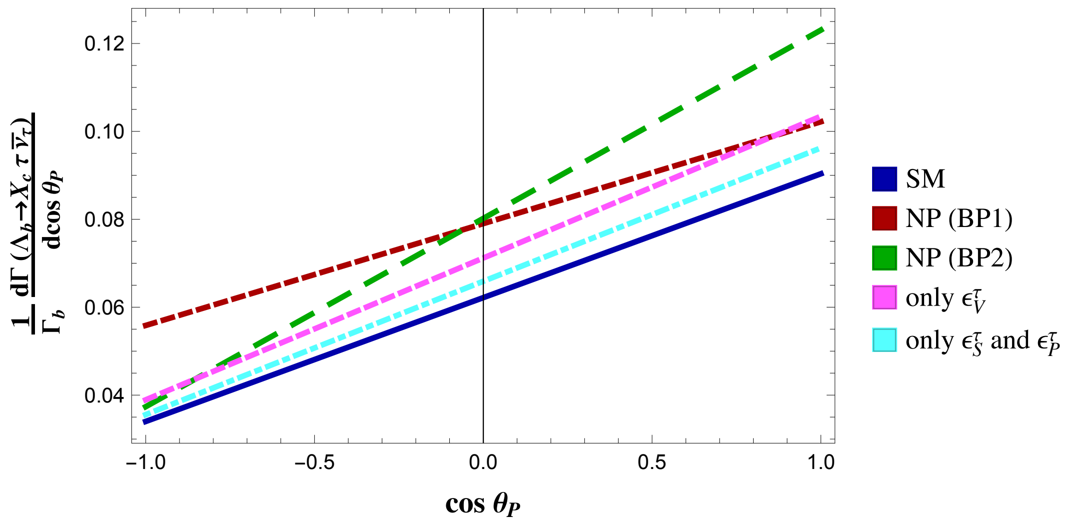

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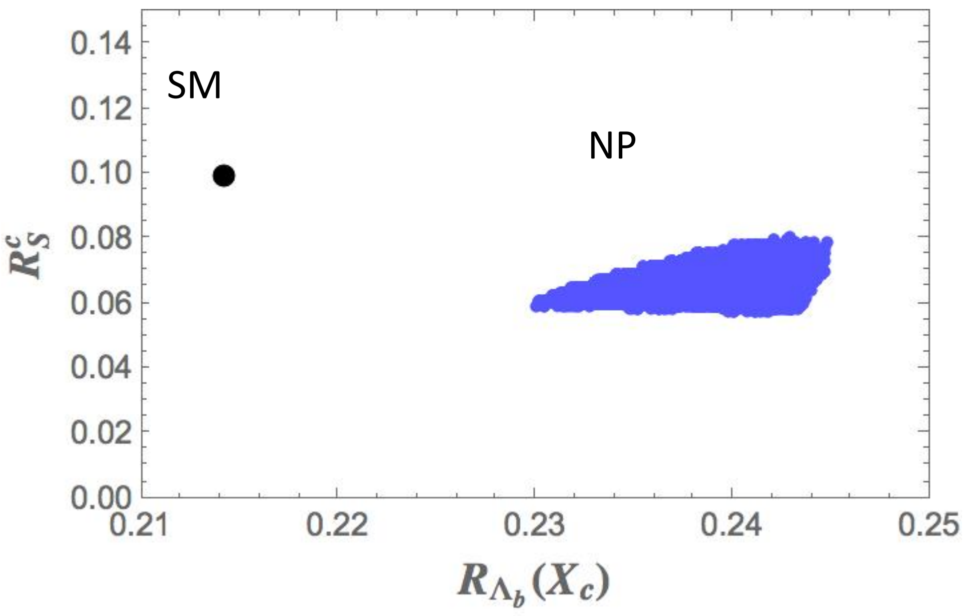
slope ratios for $\ell=\tau$ and $\ell=\mu$

$$R_{\Lambda_b}(X_u)^{SM} = 0.234$$
$$R_{\Lambda_b}(X_c)^{SM} = 0.214$$



- clean observable but hard to measure at LHC
- possible using polarized Λ_b from Z decays at FCC-e or muon collider

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Conclusions

Inclusive heavy hadron decays

- Further testing ground for NP
- Essential to understand the inclusive/exclusive discrepancy in the V_{cb} and V_{ub} determinations

Theoretical improvement:
calculation of the necessary hadronic matrix elements in the case of a polarized baryon at $O(1/m_b^3)$ and including all possible NP operators

Results: distributions in cos (θ_P) sensitive to NP
- Ratio $R(\Lambda_b)$ can deviate from SM
- Ratio of slope parameter to be considered together with $R(\Lambda_b)$
- correlation between the two ratio shows the predicted pattern of deviation from SM
- measurable at FCC