$\Lambda_b \to \Lambda(\to N\pi)\ell^+\ell^-$

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based on 1410.2115
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- $\Gamma_\Lambda \simeq 2.5 \cdot 10^{-6}$ eV: small width approximation fully applicable (compare $B \to K\pi\ell^+\ell^-$ where non-res. P-wave contributions are unconstrained)
- doubly weak decay: complementary constraints on $b \to s\ell^+\ell^-$ physics with respect to $B \to K^*\ell^+\ell^-$

Kinematics and Decay Topology

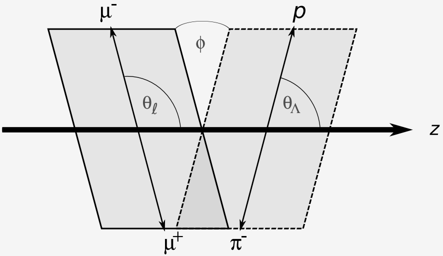
Consider the decay chain

$$\Lambda_b(p) \to \Lambda(k)\,[\to N(k_1)\,\pi(k_2)]\,\ell^+(q_1)\,\ell^-(q_2)$$

- LHCb measured Λ_b polarization in $\Lambda_b \to \Lambda J/\psi$ [LHCb 1302.5578]
  - polarization small and compatible with zero
  - consider only unpolarized Λ_b decays

for unpolarized decays

- define angles just as in $B \to K^*(\to K\pi)\ell^+\ell^-$
  - two helicity angles θ_ℓ, θ_Λ
  - one azimuthal angle ϕ



$\Lambda_b \to \Lambda$ Hadronic Matrix Elements

Form Factors ...

- using (overall 10) helicity form factors (FFs) [compare Feldmann/Yip 1111.1844]
- for lepton mass $m_\ell \to 0$ only 8 independent FFs enter observables

... from the Lattice (large q^2 only)

- results available in HQET limit[Detmold/Lin/Meinel/Wingate 1212.4827]
  - heavy quark spin symmmetry reduces matrix elements to 2 FFs at leading power
- results for *all FFs* expected (see recent progress on $\Lambda_b \to p$ form factors)

... from Sum Rules (small q^2 only)

- estimates from SCET sum rules [Feldmann/Yip 1111.1844]

$\Lambda \to N\pi$ Hadronic Matrix Element

- $\Lambda \to N\pi$ is a parity-violating weak decay
- branching fraction $\mathcal{B}[\Lambda \to N\pi] = (99.7 \pm 0.1)\%$ [PDG, our naive average]

- equations of motions reduce independent matrix elements to 2
- we choose to express them through
  - decay width Γ_Λ
  - parity-violating coupling α

- within small width approximation, Γ_Λ cancels
- α well known from experiment: $\alpha_{p\pi^-} = 0.642 \pm 0.013$ [PDG average]

Angular Distribution of $\Lambda_b \to \Lambda[\to N\pi]\ell^+\ell^-$

define the angular distribution as

$$\frac{8\pi}{3}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}q^2\,\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_\Lambda\,\mathrm{d}\phi} \equiv K(q^2, \cos\theta_\ell, \cos\theta_\Lambda, \phi)$$

similar to [Krüger/Matias hep-ph/0502060]

for the full basis of mass-dimension-six operators

$$\begin{aligned}
K = 1 &\left(K_{1ss}\sin^2\theta_\ell + K_{1cc}\cos^2\theta_\ell + K_{1c}\cos\theta_\ell\right)\\
+\cos\theta_\Lambda &\left(K_{2ss}\sin^2\theta_\ell + K_{2cc}\cos^2\theta_\ell + K_{2c}\cos\theta_\ell\right)\\
+\sin\theta_\Lambda\sin\phi &\left(K_{3sc}\sin\theta_\ell\cos\theta_\ell + K_{3s}\sin\theta_\ell\right)\\
+\sin\theta_\Lambda\cos\phi &\left(K_{4sc}\sin\theta_\ell\cos\theta_\ell + K_{4s}\sin\theta_\ell\right)
\end{aligned}$$

$$K_n \equiv K_n(q^2)$$

Angular Observables K_n

- matrix elements parametrized through 8 transversity amplitudes $A^{\lambda}_{\chi_M}$

$$A^R_{\perp_1}\,,\ A^R_{\parallel_1}\,,\ A^R_{\perp_0}\,,\ A^R_{\parallel_0}\,,\ \text{and } (R \leftrightarrow L)$$

λ dilepton chirality

χ transversity state, similar as in $B \to K^* \ell^+ \ell^-$

M |third component| of dilepton angular momentum

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- express angular observables through transversity amplitudes, e.g.

$$K_{1cc} = \frac{1}{2}\left[|A^R_{\perp_1}|^2 + |A^R_{\|_1}|^2 + (R \leftrightarrow L)\right]$$
$$K_{2c} = \frac{\alpha}{2}\left[|A^R_{\perp_1}|^2 + |A^R_{\|_1}|^2 - (R \leftrightarrow L)\right]$$
$$\vdots$$

full list in the backups

Constraints on the Wilson Coefficients

(illustrated at hand of the low recoil region)

- recover types of constraints that emerge in $B \to K^* \ell^+ \ell^-$
  - decay width

$$\Gamma = 2K_{1ss} + K_{1cc} \sim \rho_1^{\pm}$$

  - leptonic forward-backward asymmetry

$$A_{\mathrm{FB}}^{\ell} = \frac{3}{2} \frac{K_{1c}}{2K_{1ss} + K_{1cc}} \sim \rho_2$$

- find further types of constraints
  - combined forward-backward asymmetry

$$A_{\mathrm{FB}}^{\ell\Lambda} = \frac{3}{4} \frac{K_{2c}}{2K_{1ss} + K_{1cc}} \sim \rho_3^{\pm}$$

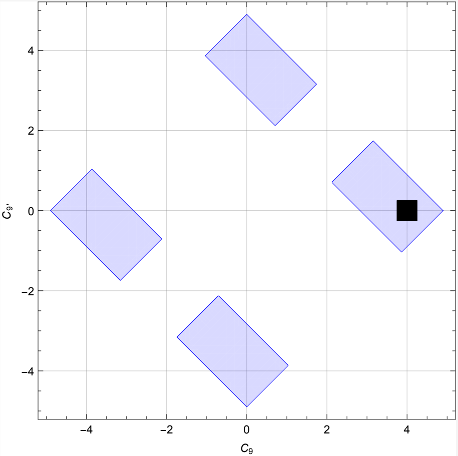
  - hadronic forward-backward asymmetry

$$A_{\mathrm{FB}}^{\Lambda} = \frac{1}{2} \frac{2K_{2ss} + K_{2cc}}{2K_{1ss} + K_{1cc}} \sim \rho_4$$

  - Re (ρ_3^-) and Re (ρ_4) also emerge in non-resonant $B \to K\pi\ell^+\ell^-$, but at the expense of imaginary parts of the $B \to K\pi$ form factors
    [Das/Hiller/Jung/Shires 1406.6681]

Constraints on the Wilson Coefficients [Sketch only!]

constrain free-floating $\mathcal{C}_{9(9')}$, fix $\mathcal{C}_{10(10')} = \mathcal{C}^{\text{SM}}_{10(10')} \simeq (-4, 0)$



use constraints based on
$\mathcal{C}_9 = \mathcal{C}_9^{\text{SM}} - 1, \mathcal{C}_{9'} = 1$

- existing constraints
  - $\rho_1^{\pm}$ blue banded constraints

black square: SM point

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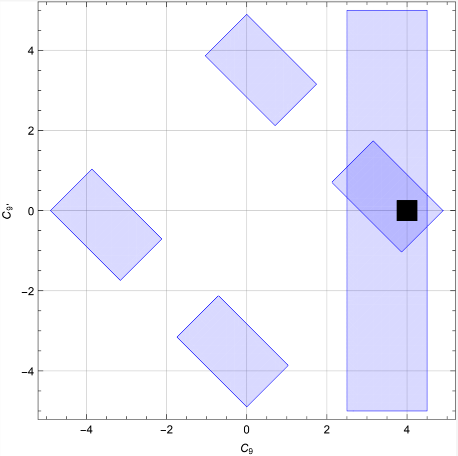

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ρ_2 blue banded constraints

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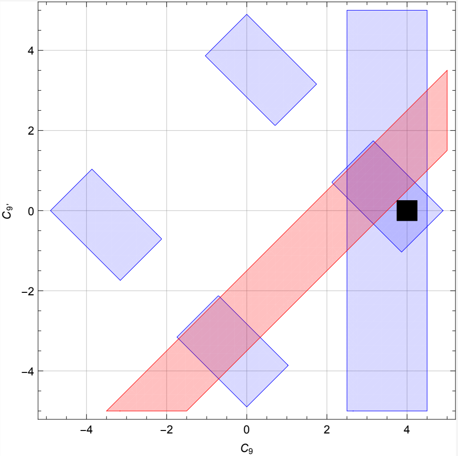

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- new complementary constraints
  - ρ_3^{-} red banded constraints

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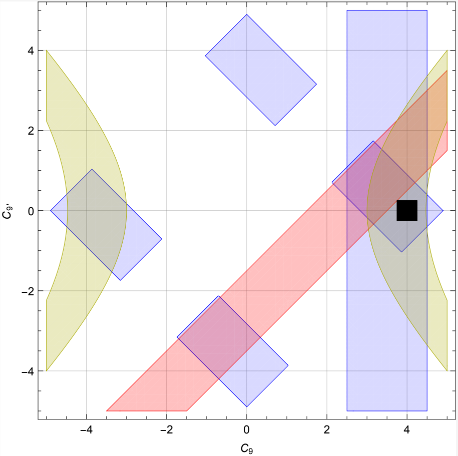

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  - ρ_4 gold hyperbolic constraint

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Standard Model vs Measurement

for the bin $15\,\mathrm{GeV}^2 \leq q^2 \leq q^2_{\text{max}}$

using the $b \to s\ell^+\ell^-$ OPE at low recoil

$$\langle \mathcal{B} \rangle = \left(4.5 \pm 1.2\right) \cdot 10^{-7}$$
$$\langle A_{\text{FB}}^{\ell} \rangle = -0.29 \pm 0.05$$
$$\langle A_{\text{FB}}^{\Lambda} \rangle = -0.26 \pm 0.03$$
$$\langle A_{\text{FB}}^{\ell\Lambda} \rangle = +0.13^{+0.02}_{-0.03}$$

measurement [LHCb 1503.07138]

$$\langle \mathcal{B} \rangle = \left(5.9 \pm 1.4\right) \cdot 10^{-7}$$
$$\langle A_{\text{FB}}^{\ell} \rangle = -0.05 \pm 0.09$$
$$\langle A_{\text{FB}}^{\Lambda} \rangle = -0.29 \pm 0.08$$
$\langle A_{\text{FB}}^{\ell\Lambda} \rangle =$ not meas.

Backup Slides

$\Lambda_b \to \Lambda(\to N\pi)\ell^+\ell^-$ Angular Observables

$$K_{1ss} = \frac{1}{4}\left[|A^R_{\perp_1}|^2 + |A^R_{\|_1}|^2 + 2|A^R_{\perp_0}|^2 + 2|A^R_{\|_0}|^2 + (R \leftrightarrow L)\right]$$

$$K_{1cc} = \frac{1}{2}\left[|A^R_{\perp_1}|^2 + |A^R_{\|_1}|^2 + (R \leftrightarrow L)\right]$$

$$K_{1c} = -\,\mathrm{Re}\left(A^R_{\perp_1} A^{*R}_{\|_1} - (R \leftrightarrow L)\right)$$

$$K_{2ss} = -\frac{\alpha}{2}\,\mathrm{Re}\left(A^R_{\perp_1} A^{*R}_{\|_1} + 2A^R_{\perp_0} A^{*R}_{\|_0} + (R \leftrightarrow L)\right)$$

$$K_{2cc} = -\alpha\,\mathrm{Re}\left(A^R_{\perp_1} A^{*R}_{\|_1} + (R \leftrightarrow L)\right)$$

$$K_{2c} = \frac{\alpha}{2}\left[|A^R_{\perp_1}|^2 + |A^R_{\|_1}|^2 - (R \leftrightarrow L)\right]$$

$$K_{3sc} = -\frac{\alpha}{\sqrt{2}}\,\mathrm{Im}\left(A^R_{\perp_1} A^{*R}_{\perp_0} - A^R_{\|_1} A^{*R}_{\|_0} + (R \leftrightarrow L)\right)$$

$$K_{3s} = -\frac{\alpha}{\sqrt{2}}\,\mathrm{Im}\left(A^R_{\perp_1} A^{*R}_{\|_0} - A^R_{\|_1} A^{*R}_{\perp_0} + (R \leftrightarrow L)\right)$$

$$K_{4sc} = \frac{\alpha}{\sqrt{2}}\,\mathrm{Re}\left(A^R_{\perp_1} A^{*R}_{\perp_0} - A^R_{\|_1} A^{*R}_{\|_0} + (R \leftrightarrow L)\right)$$

$$K_{4s} = \frac{\alpha}{\sqrt{2}}\,\mathrm{Re}\left(A^R_{\perp_1} A^{*R}_{\|_0} - A^R_{\|_1} A^{*R}_{\perp_0} - (R \leftrightarrow L)\right)$$

$\Lambda_b \to \Lambda$ Amplitudes at Low Recoil

$$A_{\perp_1}^{L(R)} = -2NC_+^{L(R)} f_\perp^V \sqrt{s_-} \qquad A_{\parallel_1}^{L(R)} = +2NC_-^{L(R)} f_\perp^A \sqrt{s_+}$$

$$A_{\perp_0}^{L(R)} = +\sqrt{2}NC_+^{L(R)} f_0^V \frac{m_{\Lambda_b} + m_\Lambda}{\sqrt{q^2}} \sqrt{s_-} \qquad A_{\parallel_0}^{L(R)} = -\sqrt{2}NC_-^{L(R)} f_0^A \frac{m_{\Lambda_b} - m_\Lambda}{\sqrt{q^2}} \sqrt{}$$

with $s_\pm = (m_{\Lambda_b} \pm m_\Lambda)^2 - q^2$

$$C_+^{R(L)} = \left((\mathcal{C}_9 + \mathcal{C}_{9'}) + \frac{2\kappa m_b m_{\Lambda_b}}{q^2}(\mathcal{C}_7 + \mathcal{C}_{7'}) \pm (\mathcal{C}_{10} + \mathcal{C}_{10'})\right)$$

$$C_-^{R(L)} = \left((\mathcal{C}_9 - \mathcal{C}_{9'}) + \frac{2\kappa m_b m_{\Lambda_b}}{q^2}(\mathcal{C}_7 - \mathcal{C}_{7'}) \pm (\mathcal{C}_{10} - \mathcal{C}_{10'})\right)$$

κ as in [Grinstein/Pirjol hep-ph/0404250]

ρs

$$
\begin{aligned}
\rho_1^\pm &= |\mathcal{C}_{79} \pm \mathcal{C}_{7'9'}|^2 + |\mathcal{C}_{10} \pm \mathcal{C}_{10'}|^2 \\
\rho_2 &= \text{Re}\,(\mathcal{C}_{79}\mathcal{C}_{10}^* - \mathcal{C}_{7'9'}\mathcal{C}_{10'}^*) - i\,\text{Im}\,(\mathcal{C}_{79}\mathcal{C}_{7'9'}^* + \mathcal{C}_{10}\mathcal{C}_{10'}^*) \\
\rho_3^\pm &= 2\,\text{Re}\,((\mathcal{C}_{79} \pm \mathcal{C}_{7'9'})(\mathcal{C}_{10} \pm \mathcal{C}_{10'})^*) \\
\rho_4 &= \left(|\mathcal{C}_{79}|^2 - |\mathcal{C}_{7'9'}|^2 + |\mathcal{C}_{10}|^2 - |\mathcal{C}_{10'}|^2\right) - i\,\text{Im}\,(\mathcal{C}_{79}\mathcal{C}_{10'}^* - \mathcal{C}_{7'9'}\mathcal{C}_{10}^*)\ .
\end{aligned}
$$