Rare Heavy Baryon decays

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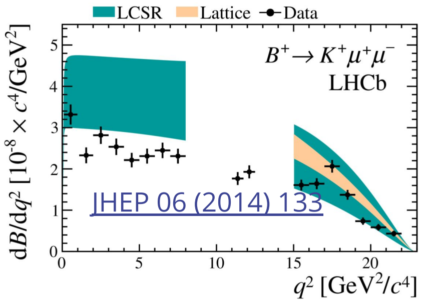
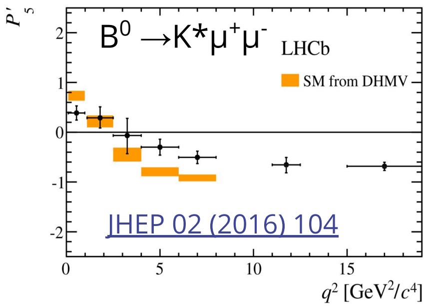
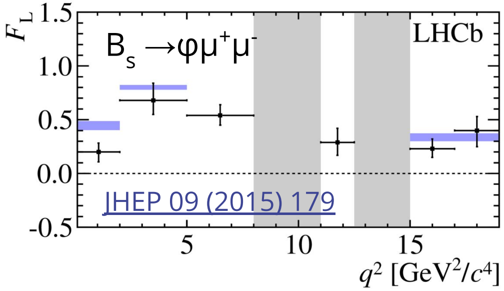
Intriguing deviations in rare B decays

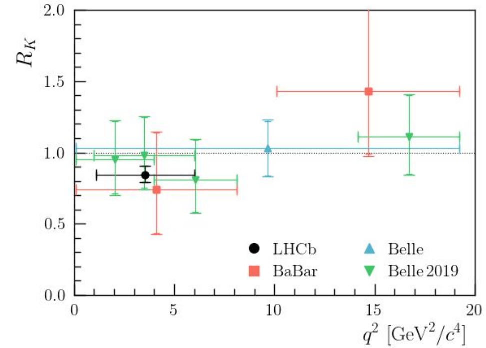
Differential BR and angular distributions

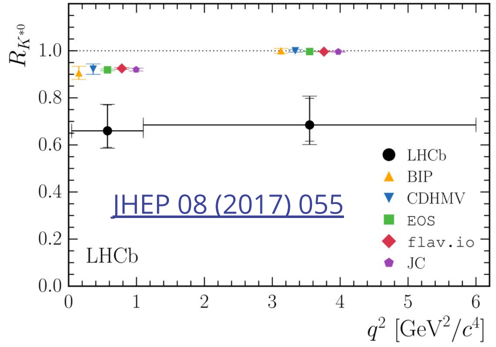






Lepton Flavour Universality (LFU) tests





Effective Hamiltonian (b → sll)

Effective theory for b → sll transitions. Separation of short and long distance at a scale $\mu = \mathcal{O}(m_b)$

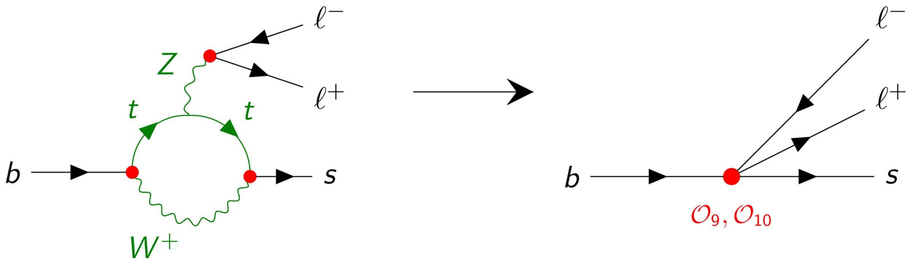
- Non-local high energy processes are reduce to local operators as in Fermi Theory.

$$\mathcal{H}_{\text{eff}}(b \to s\ell^+\ell^-) = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i \mathcal{C}_i \mathcal{O}_i$$

- With the SM operators relevant for this analysis

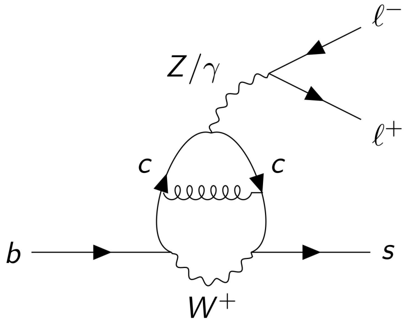
$$\mathcal{O}_7 = \frac{e}{g^2} m_b (\bar{s}\sigma_{\mu\nu} P_R b) F^{\mu\nu} \qquad \mathcal{O}_9 = \frac{e^2}{g^2} (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell) \qquad \mathcal{O}_{10} = \frac{e^2}{g^2} (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)$$

- Wilson coefficients (Ci) contain short distance dynamics.
- They are accurately computed in SM and would deviate in presence of NP. Operators absent or suppressed in the SM, can be introduced by NP.



Attention!
Not all contributions become local within the effective Hamiltonian approach. One is particularly relevant phenomenological.

$c\bar{c}$ contributions



- Two manifestations of this contribution:
  - Resonant (Charmonia, non perturbative QCD)
  - Non-Resonant (Approximated with perturbative QCD)
- These contributions appear as a correction to C_9, they are q^2 dependent and depend on external states.

- For now we include **only perturbative QCD**
- LCSR could be used to determine corrections near the $q^2 = 0$ region.
- We could also follow the strategy used by Bobeth et al. [1707.07305] to parametrize $c\bar{c}$ contributions and obtain these parameters from experiment at J/Ψ and $\Psi(2S)$ poles where we expect NP to be negligible. This requires a lot of experimental data for the resonances, and some (limited) theory input.

What has been done until now?

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

- An angular analysis has been done by Böer et al. [1410.2115] and an extension for polarized Λb was done by Blake et al. [1710.00746]
- Form factors for the Λb → Λ transition have been obtained via Lattice QCD by Detmold et al. [1602.01399]

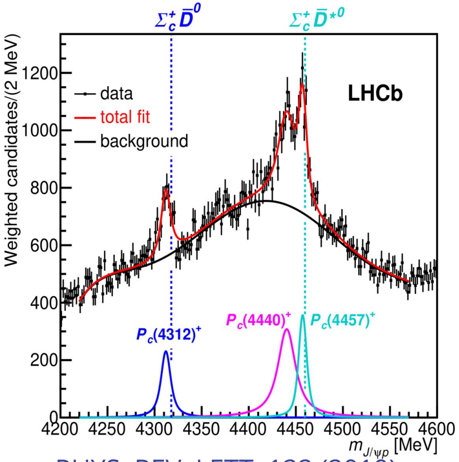
$$\Lambda_b \to \Lambda^*(\to Kp)\ell^+\ell^-$$

- An angular analysis as been done by Descotes-Genon et al. [1903.00448]
- In the case of the Λb → Λ* transition preliminary results are available from Lattice by Meinel et al. [1608.08110]

We will explain first the analysis for Λb → Λ* and then show the differences with Λb → Λ since they both share many features.

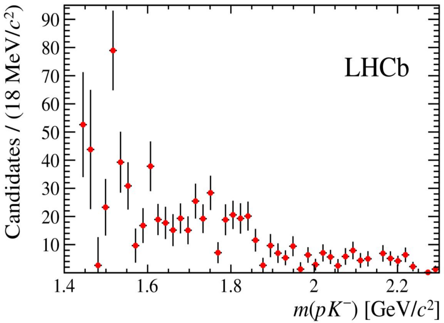
Λ_b decays at LHCb

$\Lambda_b \rightarrow pKJ/\psi$



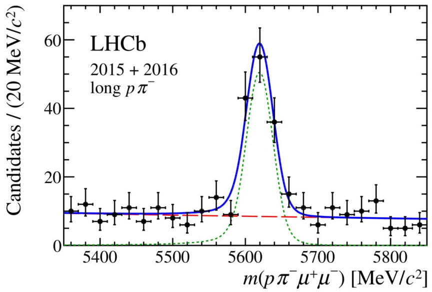
[PHYS. REV. LETT. 122 (2019) 222001]

$\Lambda_b \rightarrow pK\mu^+\mu^-$



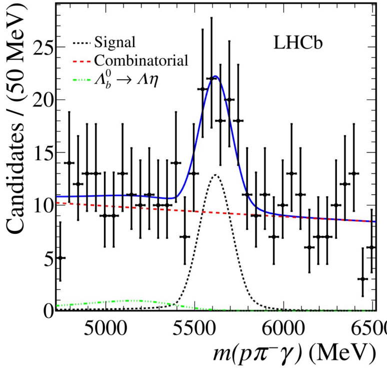
[JHEP 06 (2017) 108]

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



[JHEP 09 (2018) 146]

$\Lambda_b \rightarrow \Lambda^0\gamma$

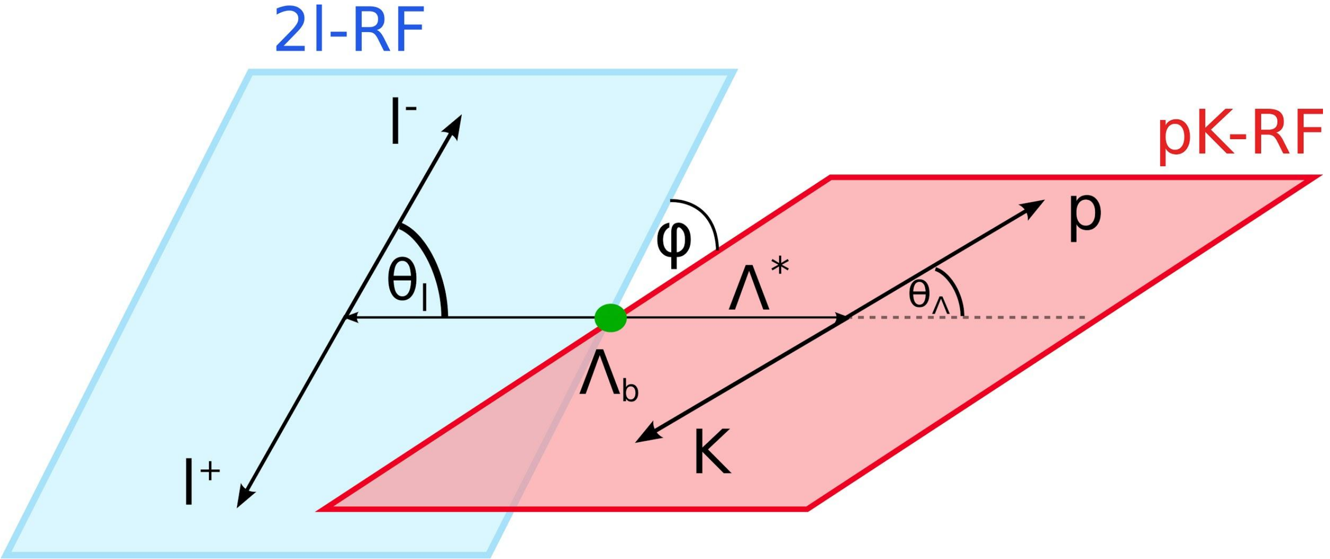


[PHYS. REV. LETT. 123 (2019) 031801]

pK final states provide largest stats → will focus on this today

Angular distributions of rare baryon decays

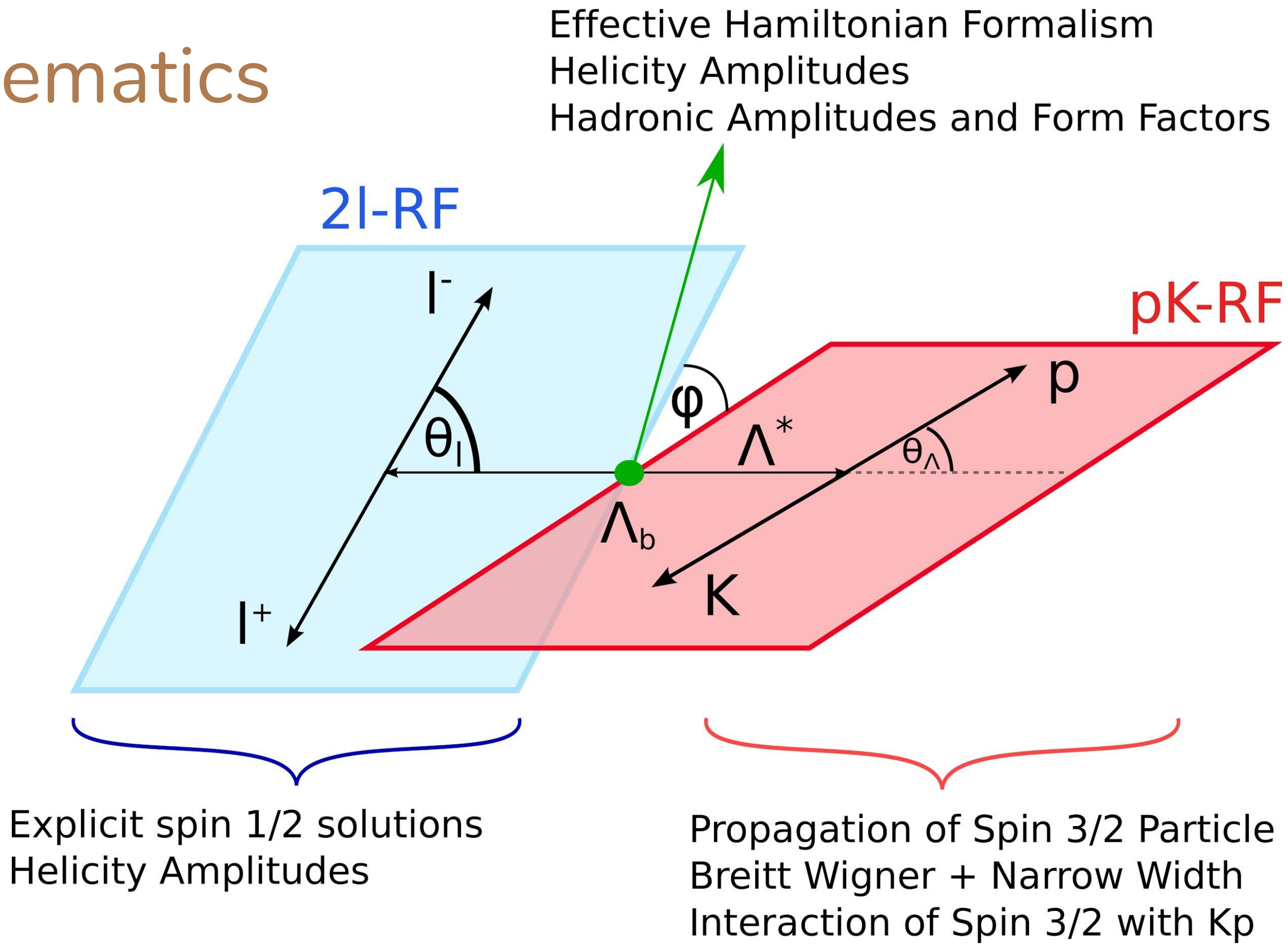
Kinematics



$$\Lambda_b(p, s_\Lambda) \to \Lambda^*(k, s_{\Lambda^*})[\to K(k_1)p(k_2, s_p)]\ell^+(q_1)\ell^-(q_2)$$

$$q \equiv q_1 + q_2 = p - k$$

Kinematics


Effective Hamiltonian Formalism
Helicity Amplitudes
Hadronic Amplitudes and Form Factors
2l-RF
pK-RF
l^-
l^+
θ_l
φ
Λ^*
θ_Λ
p
Λ_b
K
Explicit spin 1/2 solutions
Helicity Amplitudes
Propagation of Spin 3/2 Particle
Breitt Wigner + Narrow Width
Interaction of Spin 3/2 with Kp

Outline of the calculations

We separate the decay into differents steps

$$\mathcal{M}(\Lambda_b \to \Lambda^*(\to Kp)\ell^+\ell^-) = \langle \Lambda^*(\to Kp)\ell^+\ell^- | \mathcal{H}_{int} | \Lambda_b \rangle$$
$$= \sum_{s_{\Lambda^*}} \frac{\langle Kp | \mathcal{H}_{int}^{3/2} | \Lambda^*(s_{\Lambda^*}) \rangle \langle \Lambda^*(s_{\Lambda^*}) \ell^+\ell^- | \mathcal{H}_{eff} | \Lambda_b \rangle}{k^2 - m_{\Lambda^*}^2 + i m_{\Lambda^*} \Gamma_{\Lambda^*}}$$

- Step 1: Separation of hadronic and leptonic parts using the helicity amplitude approach.
- Step 2: Expression of Λb ⟶ Λ* transition in terms of form factors.
- Step 3: Λ*⟶ Kp decay, narrow width approximation, propagation and explicit solutions for Λ* (not trivial for spin 3/2).
- Step 4: Take the modulus square and multiply by the phase space.

Hadronic Amplitudes

Written as a function of form factors and all the Lorentz tensors available.

$$\langle \Lambda^* | \bar{s}\gamma^\mu b | \Lambda_b \rangle = \bar{U}_\alpha(k, s_{\Lambda^*}) \Big\{ p^\alpha \Big[F_1(q^2) p^\mu + F_2(q^2) k^\mu + F_3(q^2) \gamma^\mu \Big] + F_4(q^2) g^{\alpha\mu} \Big\} u(p, s_{\Lambda_b})$$

Usually chosen on a base that simplifies the Helicity amplitudes.

$$\begin{aligned}\langle \Lambda^* | \bar{s}\gamma^\mu b | \Lambda_b \rangle = \bar{U}_\alpha(k, s_{\Lambda^*}) \Big\{ p^\alpha \Big[& f_t^V(q^2)(M_{\Lambda_b} - m_{\Lambda^*}) \frac{q^\mu}{q^2} + f_\perp^V(q^2)(\gamma^\mu - 2\frac{m_{\Lambda^*}}{s_+} p^\mu - 2\frac{M_{\Lambda_b}}{s_+} k^\mu) \\ & + f_0^V(q^2) \frac{M_{\Lambda_b} + m_{\Lambda^*}}{s_+} (p^\mu + k^\mu - \frac{q^\mu}{q^2}(M_{\Lambda_b}^2 - m_{\Lambda^*}^2)) \Big] \\ & + f_g^V(q^2) \Big[g^{\alpha\mu} + m_{\Lambda^*} \frac{p^\alpha}{s_-} \Big(\gamma^\mu - 2\frac{k^\mu}{m_{\Lambda^*}} + 2\frac{m_{\Lambda^*} p^\mu + m_{\Lambda_b} k^\mu}{s_+} \Big) \Big] \Big\} u(p, s_{\Lambda_b})\end{aligned}$$

Λb → Λ* form factors

- **14** form factors in total
- Only preliminary results are available from lattice simulations [1608.08110]
- Quark model from [1108.6129] used for numerical illustration (educated guess of the errors).

Transversity Amplitudes

The Λb ⟶ Λ*ll decay is described by 12 transversity amplitudes.

$$TA = \left\{ B_{\perp 1}^{L(R)}, B_{\parallel 1}^{L(R)}, A_{\perp 1}^{L(R)}, A_{\parallel 1}^{L(R)}, A_{\perp 0}^{L(R)}\ A_{\parallel 0}^{L(R)} \right\}$$

$$\mathcal{C}_{9,10,-}^{L(R)} = (\mathcal{C}_9 \mp \mathcal{C}_{10}) - (\mathcal{C}_{9'} \mp \mathcal{C}_{10'})$$

$$\mathcal{C}_{9,10,+}^{L(R)} = (\mathcal{C}_9 \mp \mathcal{C}_{10}) + (\mathcal{C}_{9'} \mp \mathcal{C}_{10'})$$

$$B_{\perp 1}^{L(R)} \propto \left(\mathcal{C}_{9,10,+}^{L(R)} H_+^V(-1/2, -3/2) - \frac{2m_b(\mathcal{C}_7 + \mathcal{C}_{7'})}{q^2} H_+^T(-1/2, -3/2) \right)$$

⋮

$$A_{\parallel 0}^{L(R)} \propto \left(\mathcal{C}_{9,10,-}^{L(R)} H_0^A(+1/2, +1/2) + \frac{2m_b(\mathcal{C}_7 - \mathcal{C}_{7'})}{q^2} H_0^{T5}(+1/2, +1/2) \right)$$

Wilson Coefficients (short distance)

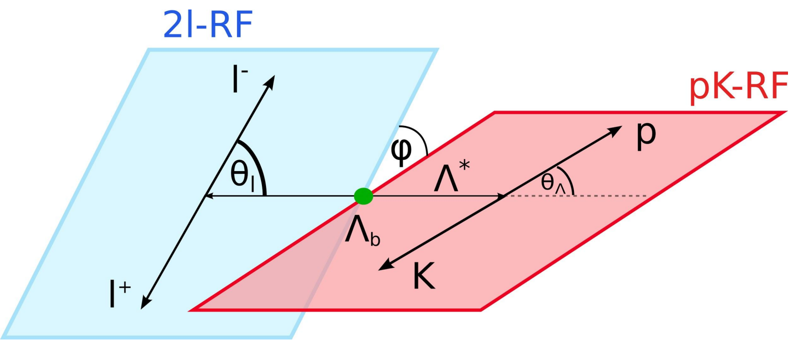
Form factors (long distance)

And their normalization is such that:

$$\frac{d\Gamma(\Lambda_b \to \Lambda^* \ell^+ \ell^-)}{dq^2} = \sum_{X \in TA} |X|^2$$

s_{Λ_b}	s_{Λ^*}	Amplitudes
$\pm\frac{1}{2}$	$\pm\frac{1}{2}$	$A_{\perp 0}^{L(R)}, A_{\parallel 0}^{L(R)}$
$\pm\frac{1}{2}$	$\mp\frac{1}{2}$	$A_{\perp 1}^{L(R)}, A_{\parallel 1}^{L(R)}$
$\pm\frac{1}{2}$	$\pm\frac{3}{2}$	$B_{\perp 1}^{L(R)}, B_{\parallel 1}^{L(R)}$

Angular Observables of Λb → Λ*(→ Kp)ll [1903.00448]



$$\frac{d^4\Gamma(\Lambda_b \to \Lambda^*(\to Kp)\ell^+\ell^-)}{dq^2 d\cos\theta_\ell d\cos\theta_\Lambda d\phi} = \frac{3}{8\pi} L(q^2, \theta_\ell, \theta_\Lambda, \phi)$$

$$\begin{aligned} L(q^2,\theta_\ell,\theta_\Lambda,\phi) = \cos^2\theta_\Lambda & \left(L_{1c}\cos\theta_\ell + L_{1cc}\cos^2\theta_\ell + L_{1ss}\sin^2\theta_\ell\right) \\ &+ \sin^2\theta_\Lambda\left(L_{2c}\cos\theta_\ell + L_{2cc}\cos^2\theta_\ell + L_{2ss}\sin^2\theta_\ell\right) \\ &+ \sin^2\theta_\Lambda\left(L_{3ss}\sin^2\theta_\ell\cos^2\phi + L_{4ss}\sin^2\theta_\ell\sin\phi\cos\phi\right) \\ &+ \sin\theta_\Lambda\cos\theta_\Lambda\cos\phi(L_{5s}\sin\theta_\ell + L_{5sc}\sin\theta_\ell\cos\theta_\ell) \\ &+ \sin\theta_\Lambda\cos\theta_\Lambda\sin\phi(L_{6s}\sin\theta_\ell + L_{6sc}\sin\theta_\ell\cos\theta_\ell) \end{aligned}$$

$$L_{1c} \propto \left(\mathrm{Re}(A^L_{\perp 1} A^{L*}_{\parallel 1}) - (L \leftrightarrow R)\right)$$

$$L_{3ss} \propto \left(\mathrm{Re}(B^L_{\parallel 1} A^{L*}_{\parallel 1}) - \mathrm{Re}(B^L_{\perp 1} A^{L*}_{\perp 1}) + (L \leftrightarrow R)\right)$$

$$\vdots$$

HQET and SCET limits simplify the form factors, fg and B amplitudes vanish.

3 independent observables. Both limits correspond to $m_b \to \infty$.

Low Recoil (HQET)

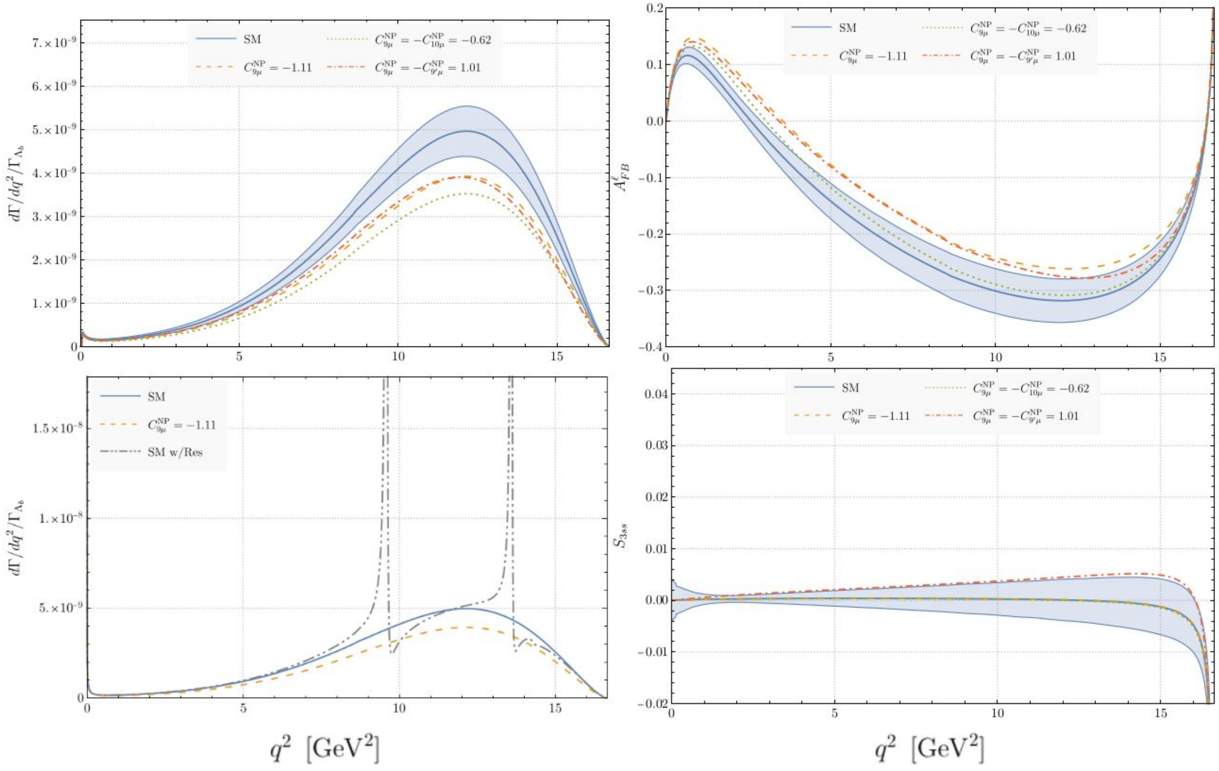
- **Two** independent form factors
- **Does not** allow us to derive non trivial ratios of observables only sensitive to Wilson coefficients.

Large recoil (SCET)

- all remaining form factors are equal
- **any ratio** of L is **optimised**

- Angular structure in agreement with Gratrex et al. [1506.03970].
- $\theta_\Lambda \to \theta_\Lambda + \pi$ symmetry related to P-conserving nature of strong decays.

$\Lambda_b \to \Lambda^*(\to Kp)ll$ Results [1903.00448]



Uncertainties (over)guesstimated, sensitivity to right-handed currents

Differences of Λb → Λ(→ pπ)ll [1410.2115]

- Only 8 transversity amplitudes present.
- 10 form factors in total, results by Detmold et al. [1602.01399].
- Λ(1115) decays mainly through **weak** interaction.

Λ decay

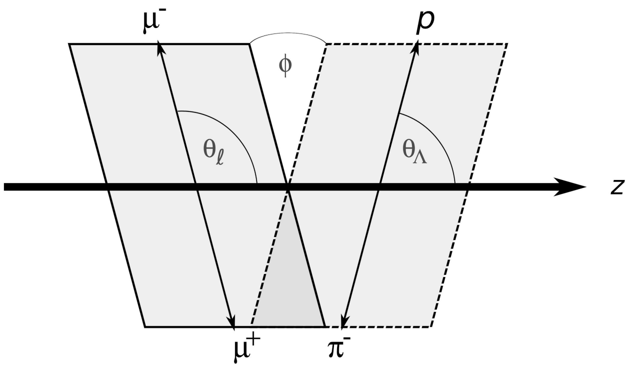
The hadronic matrix element which determines the Λ → Nπ decay can be parametrized as

$$\langle p(k_1, s_N)\pi^-(k_2)|\left[\bar{d}\gamma_\mu P_L u\right]\left[\bar{u}\gamma^\mu P_L s\right]|\Lambda(k, s_\Lambda)\rangle = \left[\bar{u}(k_1, s_N)\big(\xi\gamma_5 + \omega\big)u(k, s_\Lambda)\right]$$

where we find a parity violating term (not present for the strong decay Λ^* → pK studied before) parametrized by

$$\alpha = \frac{-2\,\mathrm{Re}(\omega\,\xi)}{\sqrt{\frac{r_-}{r_+}}\,|\xi|^2 + \sqrt{\frac{r_+}{r_-}}\,|\omega|^2} \approx 0.7 - 0.75\,.$$

Angular Observables of $\Lambda_b \to \Lambda(\to p\pi)ll$ [1410.2115]



$$\frac{d^4\Gamma(\Lambda_b \to \Lambda(\to p\pi)\ell^+\ell^-)}{dq^2 d\cos\theta_\ell d\cos\theta_\Lambda d\phi} = \frac{3}{8\pi} K(q^2, \theta_\ell, \theta_\Lambda, \phi)$$

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

- Angular structure in agreement with Gratrex et al. [1506.03970].
- $\theta_\Lambda \to \theta_\Lambda + \pi$ symmetry not present because of P-violating nature of weak decays (recovered when $\alpha \to 0$).
- Full analysis including polarized Λ_b from Blake et al. also available [1710.00746]

$$K_{1cc}(q^2) = \frac{1}{2}\left[|A^R_{\perp_1}|^2 + |A^R_{\parallel_1}|^2 + (R \leftrightarrow L)\right]$$

$$K_{2cc}(q^2) = +\alpha \mathrm{Re}\,(A^R_{\perp_1} A^{*R}_{\parallel_1}) + (R \leftrightarrow L)$$

$$\vdots$$

Angular Observables of $\Lambda_b \rightarrow \Lambda(\rightarrow p\pi)ll$ [1410.2115]

Exploiting Form-Factor Symmetries at Low Recoil (HQET)

$$X_1 \equiv \frac{K_{1c}}{K_{2cc}} = -\frac{\mathrm{Re}\ \rho_2}{\alpha\ \mathrm{Re}\ \rho_4}$$

ρi independent of form factors

$$\langle X_1 \rangle^{\mathrm{SM}} = +0.08^{+0.12}_{-0.09}$$

$$\langle X_1 \rangle^{\mathrm{BM1}} = -0.49^{+0.07}_{-0.08}$$

Sensitivity to NP

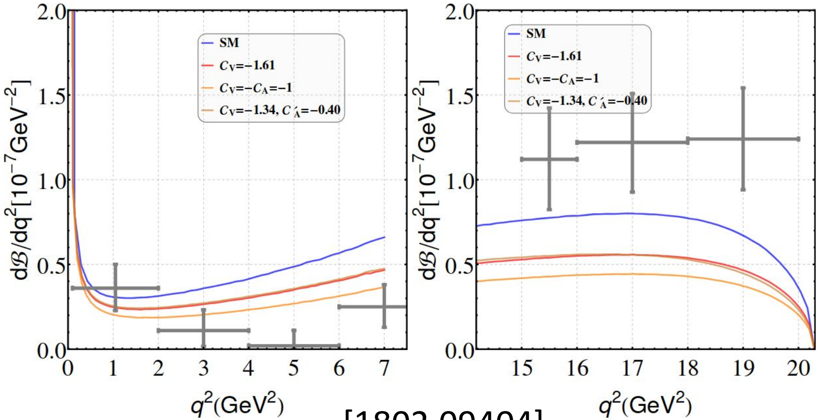
$$\mathcal{C}_9^{\mathrm{BM1}} = \mathcal{C}_9^{\mathrm{SM}} - 1$$

$$\mathcal{C}_{9'}^{\mathrm{BM1}} = 1$$

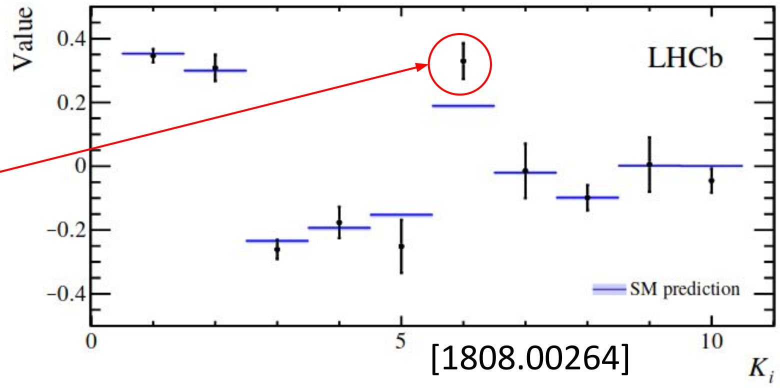
Exploiting Form-Factor Symmetries at Large recoil (SCET)

- All form factors are equal or vanish.
- Any ratio of K is optimised.

- Largest discrepancy for K_{2c}, 2.6σ from SM (too large, not physical).
- For the moment, limited sensitivity to favoured NP scenarios and agreement with the SM.



[1802.09404]



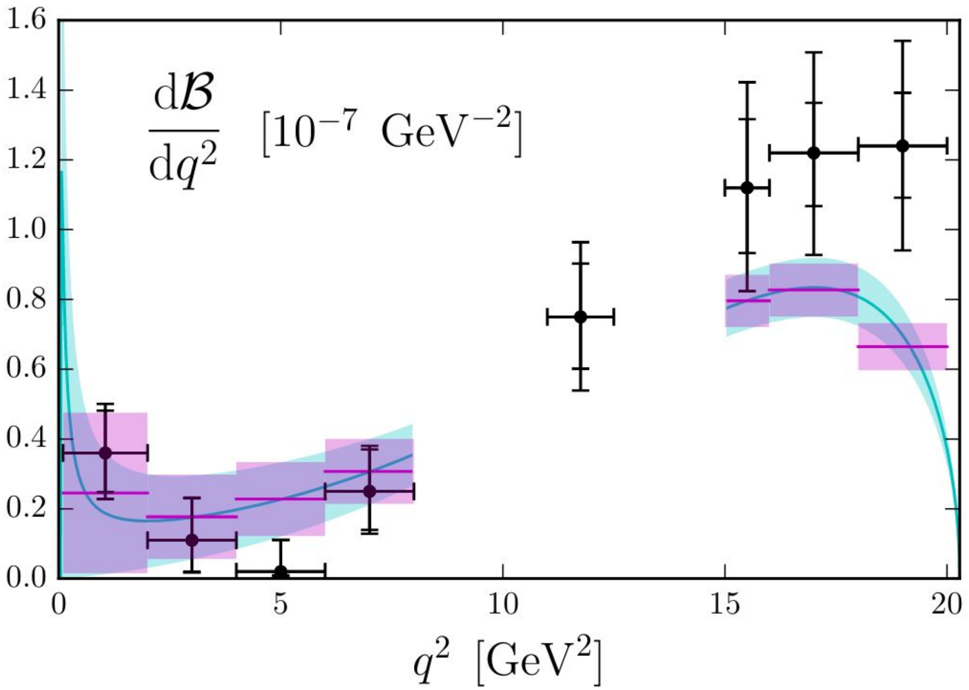
[1808.00264]

$\Lambda_b \rightarrow \Lambda(\rightarrow p\pi)\mu^+\mu^-$ results [1602.01399]

- Differential branching fraction deviation not yet statistically (1.6σ) but in the opposite direction of $B \rightarrow K^{(*)} \mu^+\mu^-$ and $B_s \rightarrow \varphi\mu^+\mu^-$ deviations (could be explained by quark-hadron duality violation or Λ_b prod fraction).

- Λ_b prod fraction could help to explain either the low or the large recoil but not both.

- A negative shift in C_9 alone (simplest scenario for mesonic observables) would further lower the predicted $\Lambda_b \rightarrow \Lambda\mu^+\mu^-$ differential branching fraction.



Connection with $\Lambda_b \to \Lambda^{(*)}\gamma$

The branching ratio for radiative decay $\Lambda_b \to \Lambda^* \gamma$ is proportional to

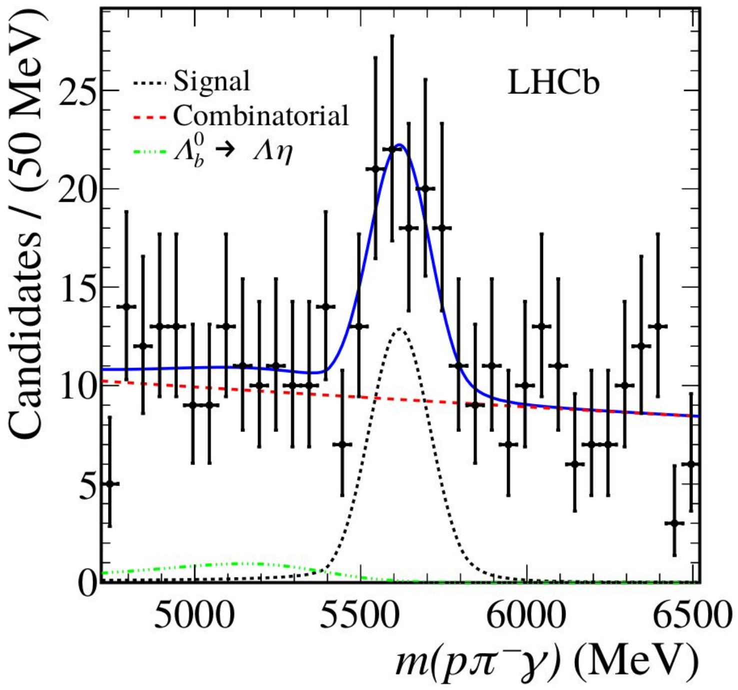
$$\lim_{q^2 \to 0} (q^2 \sum_{X=A,B} |X|^2)$$

- At $q^2 \to 0$ limit only two spin configurations contribute ($C_7^{(\prime)}$)
- Number of independent form factors reduced.

$$f_\perp^{T5}(q^2), f_\perp^{T}(q^2) \xrightarrow[q^2 \to 0]{} f_\perp^{T}(0)$$

$$f_g^{T5}(q^2), f_g^{T}(q^2) \xrightarrow[q^2 \to 0]{} f_g^{T}(0)$$

- Possibility to extract information about the form factors normalization (multiplied by C_7) from this decay.
- The same should be true for $\Lambda_b \to \Lambda(\to p\pi)\gamma$



[1904.06697]

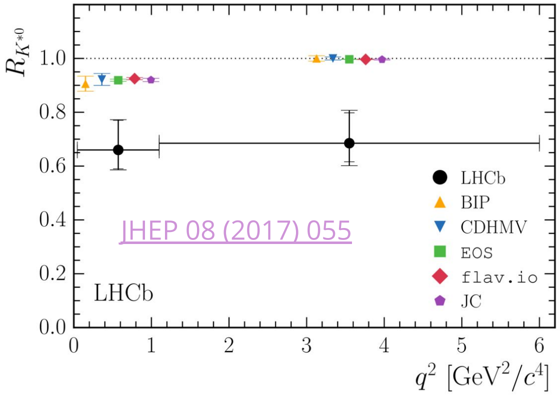
LFU test with baryons

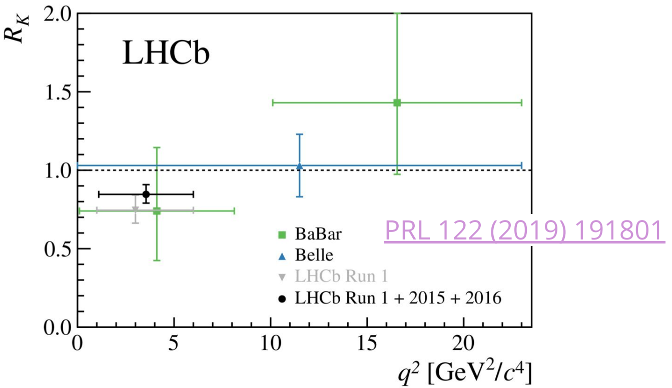
LFU tests

$$R_H = \frac{BR(B \to H\mu^+\mu^-)}{BR(B \to He^+e^-)}$$

See talks by Stagl and Abhishek et al. for interpretations

LFU tensions observed in B meson decays:





→ test also the baryon sector! $R_\phi(B_s) \approx R_{\pi K}(B) \approx R(\Lambda_b)_\Lambda \approx R(\Lambda_b)_{pK} \approx \ldots \approx R_K$

[Fuentes-Martin et al.]

R_{pK}

LFU test using $\Lambda_b \rightarrow pKl^+l^-$ decays, experimentally:

from mass fit — from MC and calibration samples

$$R_H = \boxed{\frac{N(B\to H\mu^+\mu^-)}{N(B\to He^+e^-)}} \times \boxed{\frac{\epsilon(B\to He^+e^-)}{\epsilon(B\to H\mu^+\mu^-)}}$$

- $\Lambda_b \rightarrow pK\mu^+\mu^-$ already observed with Run 1 data
- $\Lambda_b \rightarrow pKe^+e^-$ not observed to date: first challenge!
- Exploit related $\Lambda_b \rightarrow pKJ/\psi$ as control mode:
    - stringent cross-check $r_{J/\psi}$
    - measure R_{pK} as a double ratio
    - use observed pK spectrum to correct the simulation

$$r_{J/\psi} = \frac{BR(B\to HJ/\psi(\mu^+\mu^-))}{BR(B\to HJ/\psi(e^+e^-))} = 1$$

$$R_H = \frac{\dfrac{N(B\to H\mu^+\mu^-)}{N(B\to HJ/\psi(\mu^+\mu^-))}}{\dfrac{N(B\to He^+e^-)}{N(B\to HJ/\psi(e^+e^-))}} \times \frac{\dfrac{\epsilon(B\to He^+e^-)}{\epsilon(B\to HJ/\psi(e^+e^-))}}{\dfrac{\epsilon(B\to H\mu^+\mu^-)}{\epsilon(B\to HJ/\psi(\mu^+\mu^-))}}$$

R_{pK}: electrons vs muons

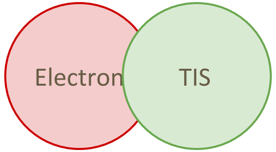
Hardware trigger

Larger ECAL occupancy → tighter thresholds for electrons:

- e p_T > 2700/2400 MeV in 2012/2016
- μ p_T > 1700/1800 MeV in 2012/2016

[LHCb-PUB-2014-046, 2019 JINST 14 P04013]

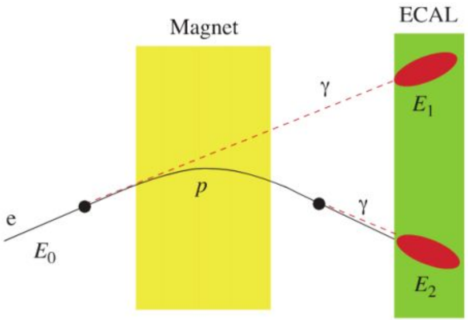
Mitigate including hadron trigger and events triggered independently of the signal (TIS)



Interaction with detector material

Electrons radiate much more Bremsstrahlung

Recovery procedure in place



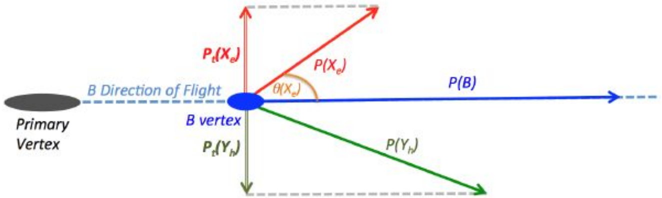
- miss some photons and add fake ones
- ECAL resolution worse than tracking

→ worse mass resolution for electron modes

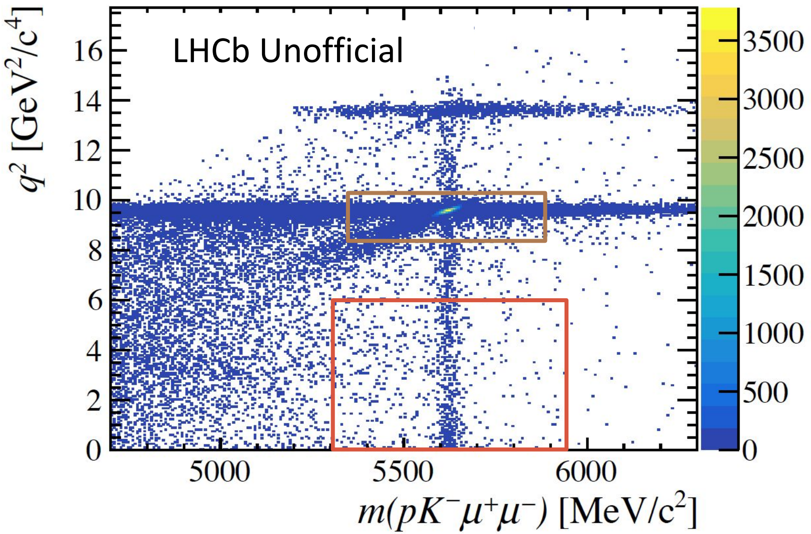
Candidate selection

LFU tensions observed in B meson decays:

- Kinematic and particle identification (PID)
- Mass vetoes for peaking backgrounds
  - $B^+ \to Kll$, $B_s \to \varphi ll$, Λ_c and D^0 decays
- BDT to reject combinatorial background
- Momentum balance for $e^\pm$ states:



$$\alpha_{HOP} = \frac{p_T(pK)}{p_T(ee)}$$



All: m(pK) < 2600 MeV

Signal region: $0.1 < q^2 < 6$ GeV^2

Control mode: J/ψ region

Efficiencies

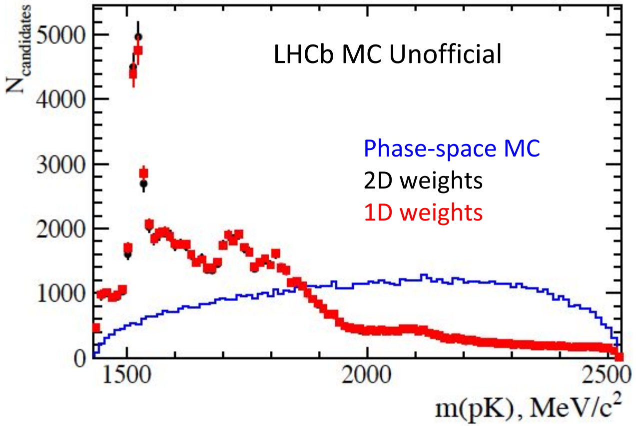
Computed from MC and calibration samples

- Decay model corrected using $\Lambda_b \to pKJ/\psi$
- PID efficiencies from calibration samples
- Event multiplicity corrected using $\Lambda_b \to pKJ/\psi$
- 2D kinematic correction: $p_T(\Lambda_b)$ vs $\eta(\Lambda_b)$
- Trigger efficiencies from control mode data

$$\epsilon_{tot} = \epsilon_{geom} \times \epsilon_{reco} \times \epsilon_{sel}$$

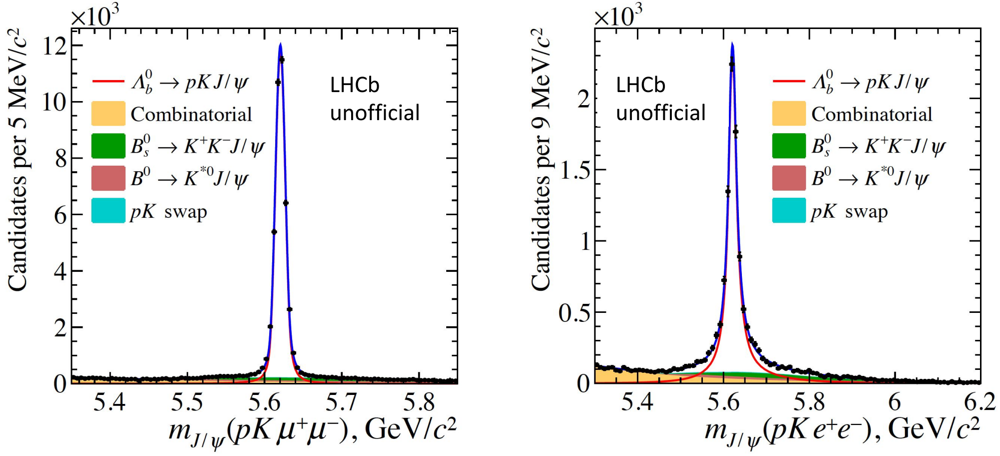
Only efficiency ratios enter our observables →
cancellation of systematics

$\Lambda_b \to pKJ/\psi$ simulation



Efficiency cross-check: $r_{J/\psi}$

$$r_{J/\psi} = \frac{N(\Lambda_b^0 \to pK J/\psi(\to \mu^+\mu^-))}{N(\Lambda_b^0 \to pK J/\psi(\to e^+e^-))} \times \frac{\epsilon(\Lambda_b^0 \to pK J/\psi(\to e^+e^-))}{\epsilon(\Lambda_b^0 \to pK J/\psi(\to \mu^+\mu^-))}$$



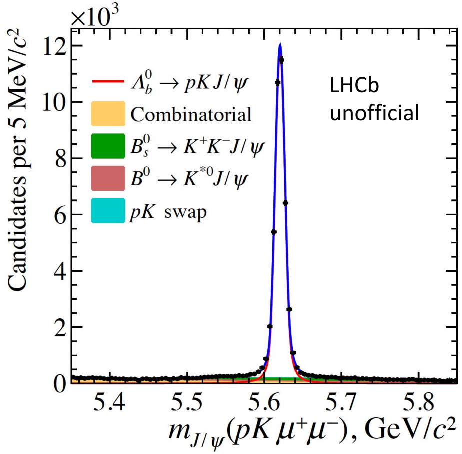
$m_{J/\psi}$ = with J/ψ mass constrain

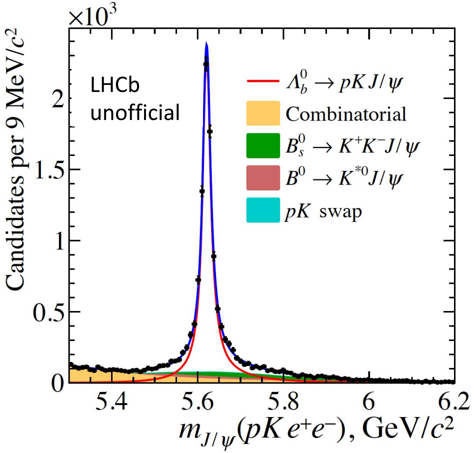
Efficiency cross-check: $r_{J/\psi}$

$$r_{J/\psi} = \frac{N(\Lambda_b^0 \to pK J/\psi(\to \mu^+\mu^-))}{N(\Lambda_b^0 \to pK J/\psi(\to e^+e^-))} \times \frac{\epsilon(\Lambda_b^0 \to pK J/\psi(\to e^+e^-))}{\epsilon(\Lambda_b^0 \to pK J/\psi(\to \mu^+\mu^-))}$$

$$r_{J/\psi} = 0.962 \pm 0.048$$

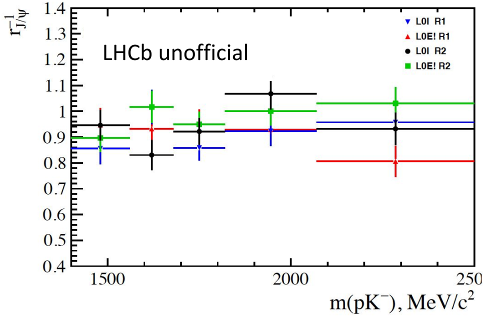
Incl. stat and syst. uncertainties

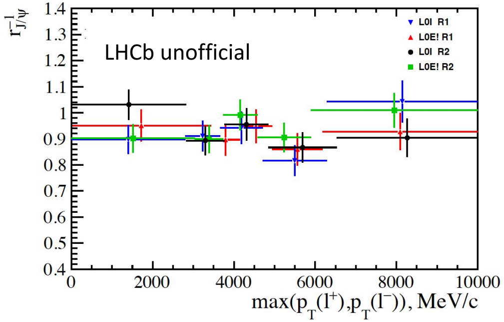




$m_{J/\psi}$ = with J/ψ mass constrain

Flat trends in relevant variables





Towards R_{pK}:

Rare electron mode $\Lambda_b \to pKee$ never observed before

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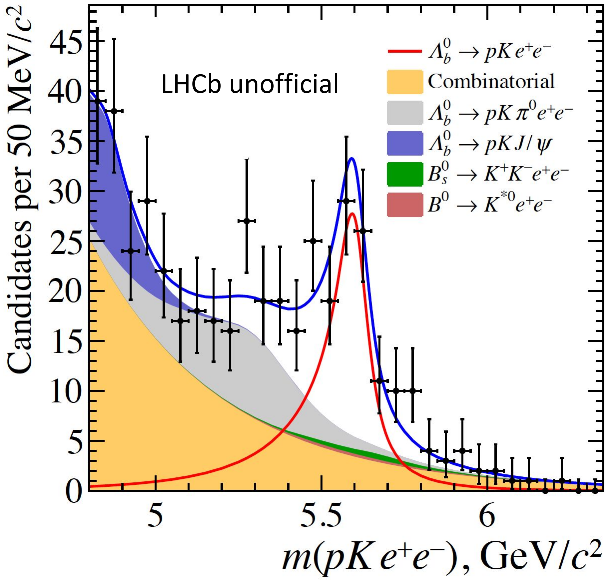
Rare electron mode $\Lambda_b \rightarrow pKee$ never observed before



Statistical significance larger than 7σ $\rightarrow$

First observation!

$N(\Lambda_b \rightarrow pKee) = 122 \pm 17$

$\sigma(R_{pK}) \sim 15\%$

Amplitude analysis of $\Lambda_b \to pK\gamma$

$\Lambda_b \to pK\gamma$

... is interesting because:

RpK: What does m_{pK} look like at q^2=0 (γ) compared to high q^2 (J/ψ)?

Pentaquarks: observed in $\Lambda_b \to pKJ/\psi$, possible in $\Lambda_b \to pK\gamma$

→ Set upper limit on pentaquarks in $p\gamma$

Data selection and backgrounds

Data selection kindly shared with us by Boris Quintana [Young Researcher Talk at GdR 2018]

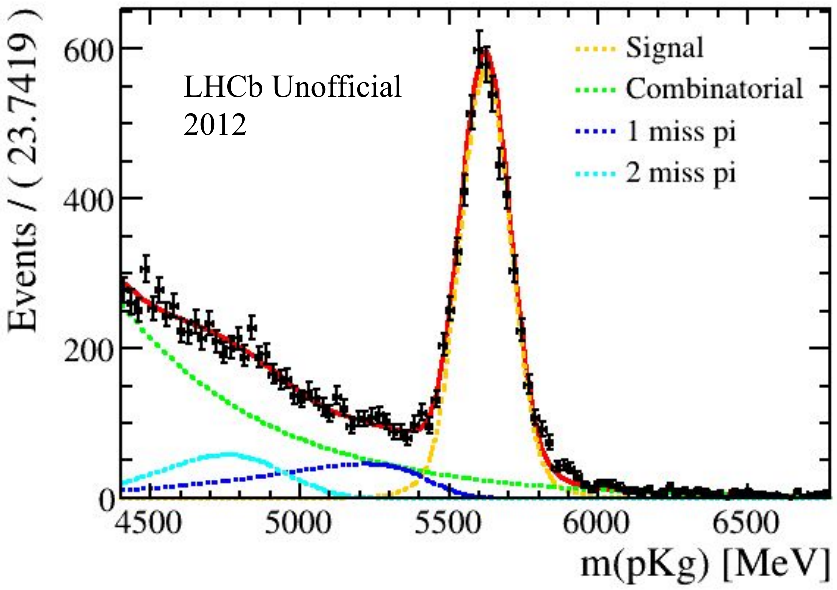
Some remaining backgrounds:

Combinatorial + missing pions

Misidentified: $B_s \rightarrow \varphi(\rightarrow KK)\gamma$

Plan: compute and apply sWeights

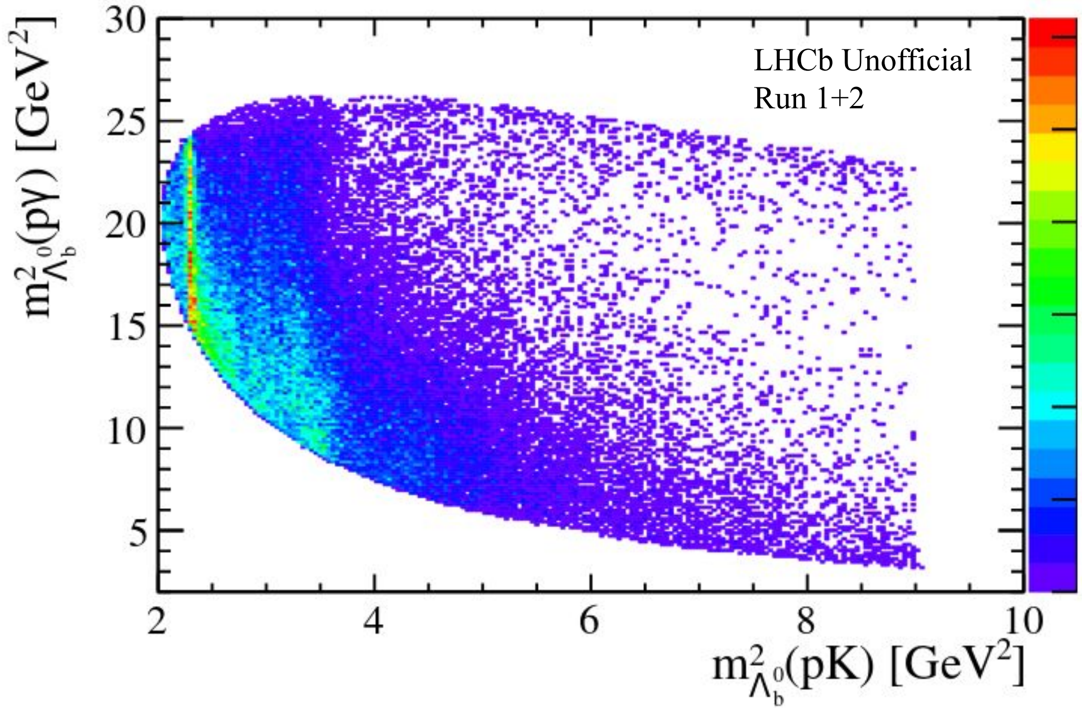
Work-in-progress: simple cut on Λ_b mass for now



Dalitz space

Clear Λ*(1520) resonance.

Everything else… not so much.



Amplitude analysis

Model: helicity formalism + isobar

Amplitude analysis

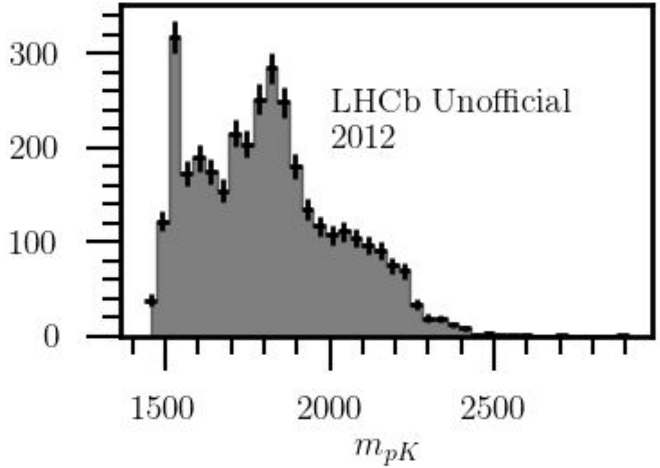
Model: helicity formalism + isobar

Wigner D: $\Lambda_b \to \Lambda^* \gamma$ Wigner D: $\Lambda^* \to pK$

$$D^{J_{\Lambda_b}}_{(\lambda_\Lambda - \lambda_\gamma) M_{\Lambda_b}}(\varphi_\Lambda \theta_\Lambda - \varphi_\Lambda) D^{J_\Lambda}_{\lambda_p \lambda_\Lambda}(\varphi_p \theta_p - \varphi_p)$$

Amplitude analysis

Model: helicity formalism + isobar



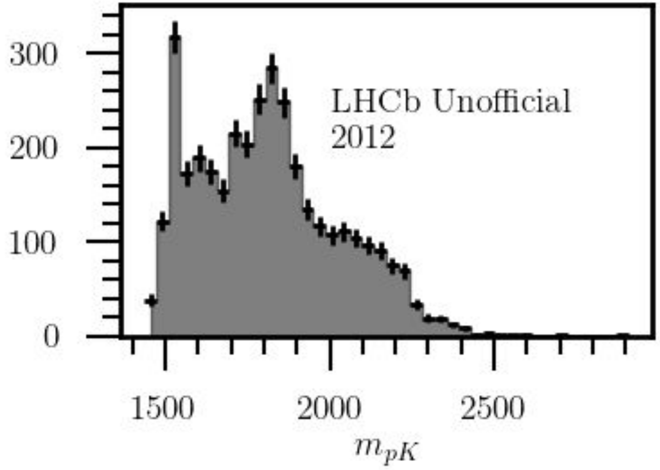
Wigner D: $\Lambda_b \to \Lambda^* \gamma$ — Wigner D: $\Lambda^* \to pK$

$$D^{J_{\Lambda_b}}_{(\lambda_\Lambda - \lambda_\gamma) M_{\Lambda_b}}(\varphi_\Lambda \theta_\Lambda - \varphi_\Lambda)\, D^{J_\Lambda}_{\lambda_p \lambda_\Lambda}(\varphi_p \theta_p - \varphi_p)$$

$$\times \sum_{L=|J_{\Lambda_b}-S|}^{|J_{\Lambda_b}+S|} \sum_{S=|J_\Lambda - J_\gamma|}^{|J_\Lambda + J_\gamma|} \left[C_1 C_2 C_3 \; h_{LS} \left(\frac{p}{M_{\Lambda_b}}\right)^L \left(\frac{q}{M_\Lambda}\right)^l B_L(p) B_l(q)\; X(m_{pK}) \right]$$

Clebsch-Gordans; fit parameter (h_{LS}); orb. ang. mom. barriers; Blatt-Weisskopf form factors; lineshape

Amplitude analysis



Model: helicity formalism + isobar

$$\overset{\text{Wigner D: }\Lambda_b\to\Lambda^*\gamma}{D^{J_{\Lambda_b}}_{(\lambda_\Lambda-\lambda_\gamma)M_{\Lambda_b}}(\varphi_\Lambda\theta_\Lambda-\varphi_\Lambda)}\;\overset{\text{Wigner D: }\Lambda^*\to pK}{D^{J_\Lambda}_{\lambda_p\lambda_\Lambda}(\varphi_p\theta_p-\varphi_p)}$$

$$\times\sum_{L=|J_{\Lambda_b}-S|}^{|J_{\Lambda_b}+S|}\;\sum_{S=|J_\Lambda-J_\gamma|}^{|J_\Lambda+J_\gamma|}\left[\underset{\text{Clebsch-Gordans}}{C_1C_2C_3}\;\overset{\text{fit parameter}}{h_{LS}}\;\underset{\text{orb. ang. mom. barriers}}{\left(\frac{p}{M_{\Lambda_b}}\right)^L\left(\frac{q}{M_\Lambda}\right)^l}\;\underset{\text{Blatt-Weisskopf form factors}}{B_L(p)B_l(q)}\;\underset{\text{lineshape}}{X(m_{pK})}\right]$$

To obtain full decay rate:

- Coherently sum possible Λ* helicities and Λ* resonances
- Incoherently sum possible proton and photon helicities and Λ_b spin projection

Full amplitude*: features and examples

Dependent on the three decay angles and m(pK)
⟶ **BUT** only two degrees of freedom

$$\frac{d\Gamma}{d\Omega_{\Lambda^*}} \propto P_{\Lambda_b} f(\Omega_{\Lambda^*})$$

⟶ No dependency on polar and azimuthal angles of Λ^* for unpolarized Λ_b
Polarization measurement: [LHCb-PAPER-2012-057]

Same parity:

$$J = \frac{1}{2} : \frac{d\Gamma}{d(\cos(\theta_p))} \propto 1$$

$$J = \frac{3}{2} : \frac{d\Gamma}{d(\cos(\theta_p))} \propto 1 + k\cos^2(\theta_p)$$

$$J = \frac{1}{2}, \frac{3}{2} : \frac{d\Gamma}{d(\cos(\theta_p))} \propto 1 + k\cos^2(\theta_p)$$

Opposite parity:

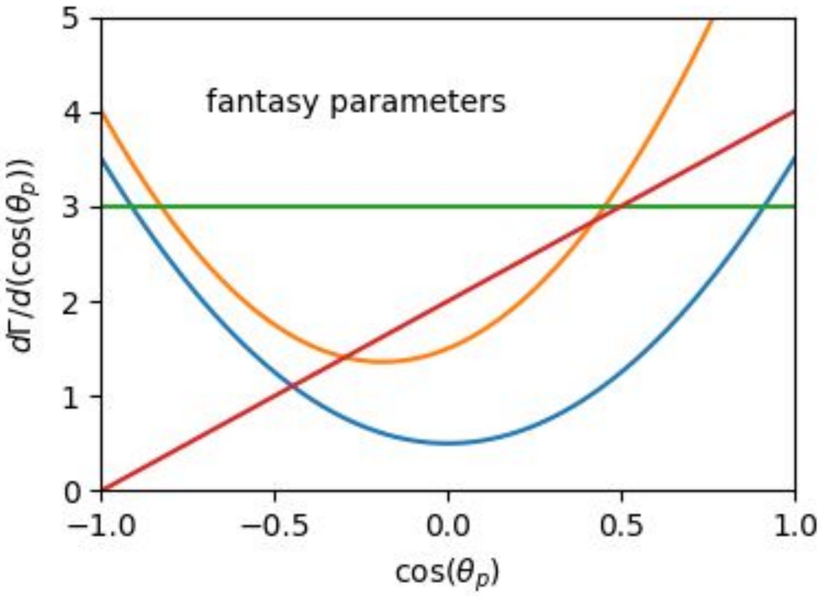
$$J = \frac{1}{2} : \frac{d\Gamma}{d(\cos(\theta_p))} \propto \cos(\theta_p)$$

$$J = \frac{3}{2} : \frac{d\Gamma}{d(\cos(\theta_p))} \propto 1 + k\cos^2(\theta_p)$$

$$J = \frac{1}{2}, \frac{3}{2} : \frac{d\Gamma}{d(\cos(\theta_p))} \propto 1 + k_1\cos(\theta_p) + k_2\cos^2(\theta_p)$$

*Nobody really wants to see that written down.

Full amplitude*: features and examples



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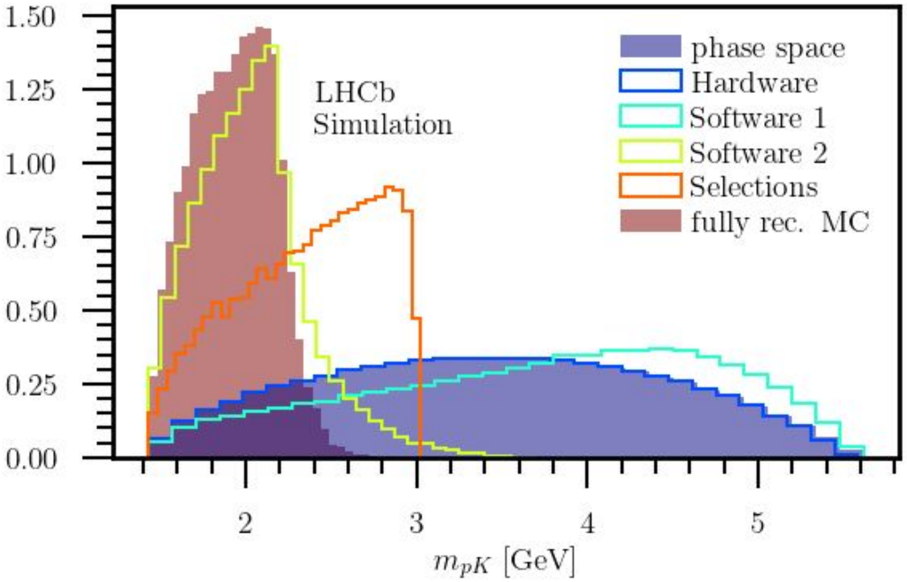
Acceptance efficiency



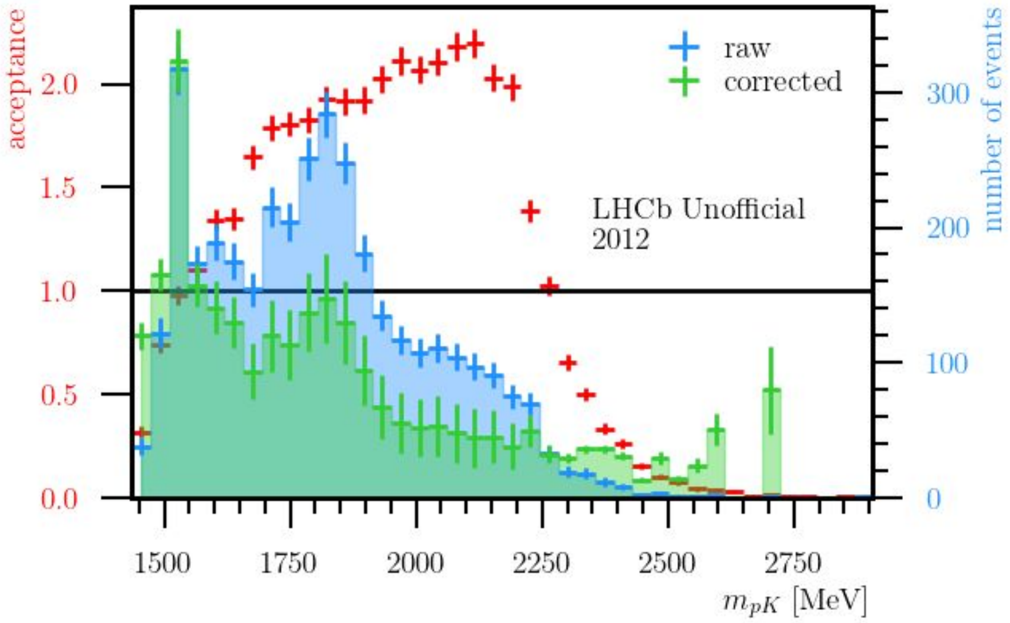
1) Generate Monte Carlo data
2) Simulate detector response
3) Apply reconstruction software
4) Apply all other selection cuts

→ known true value to every reconstructed value

→ useful to study acceptance effects

Distributions in data

Using simple bin-by-bin correction



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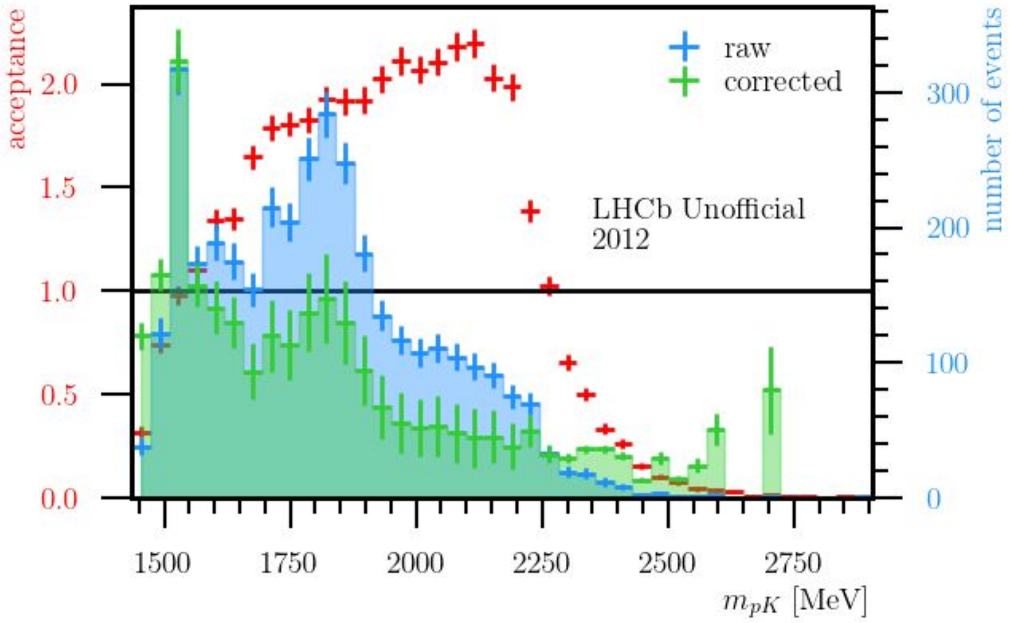

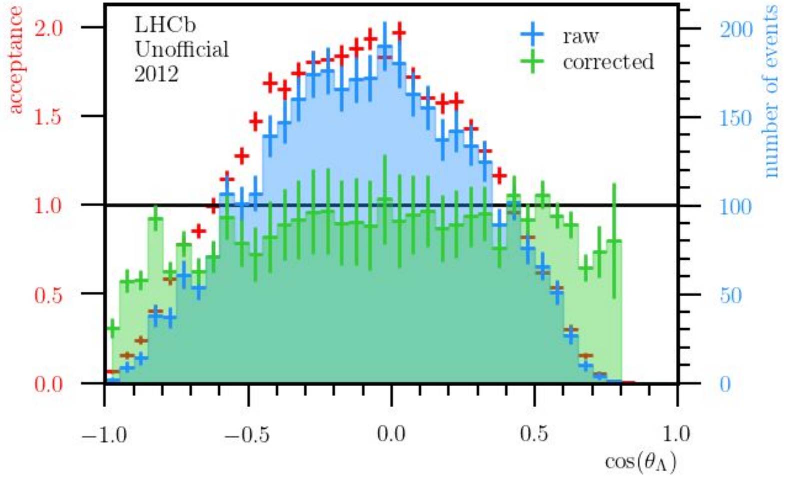

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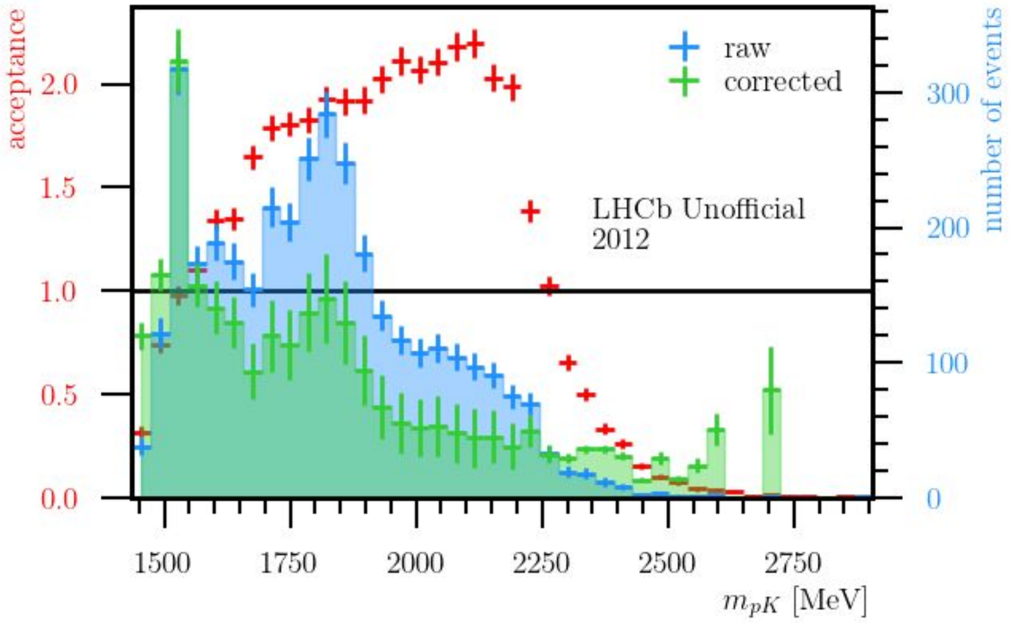

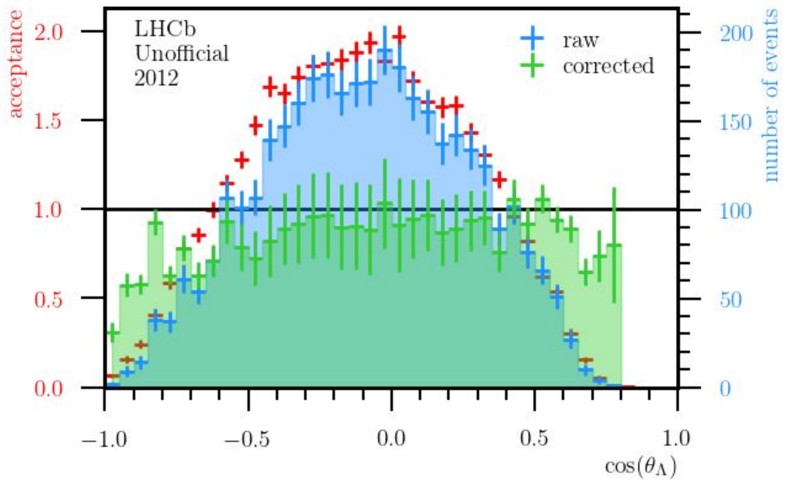

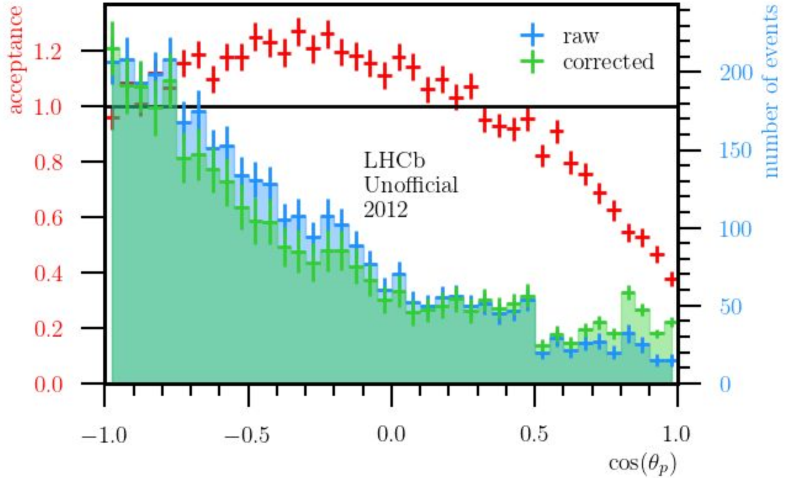

Conclusions

Conclusions

KEEP CALM AND BARYON

A lot of interest in b-baryon decays recently:

- Predictions for Λ_b rare decays to $\Lambda(J=½, 3/2)ll$
  - Form factors from lattice available for the ground state
  - Charmonium contributions need to be estimated

- Experimental measurements mostly available for the ground state, a lot of work on pK final state!
  - LFU measurement R_{pK}
  - Amplitude analysis of $\Lambda_b \to pK\gamma$ as a preamble of $\Lambda_b \to pKll$

THANKS!