Rare decays of Λ_b, B_c and other b-hadrons at LHCb

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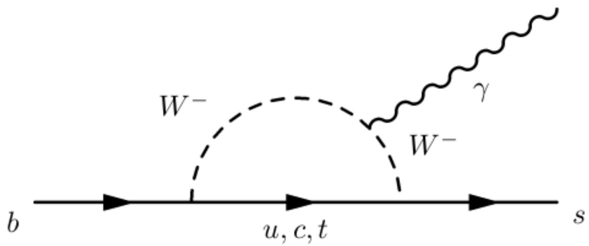
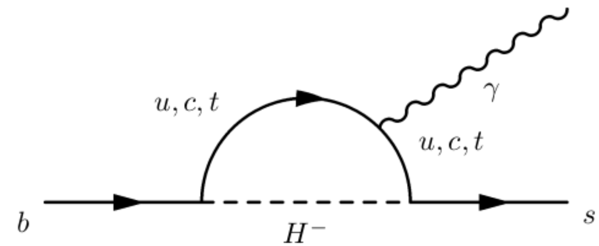
Why rare decays?

- Decays mediated by Flavour-Changing Neutral Currents: $q \rightarrow q'\gamma$, $q \rightarrow q' l^+ l^-$
  - Forbidden at tree level in the Standard Model (SM)
  - Can proceed only through amplitudes involving electroweak loop
  - Sensitive to new particles at higher scales that direct research





- New Physics contributions could enter at the same level ad SM:

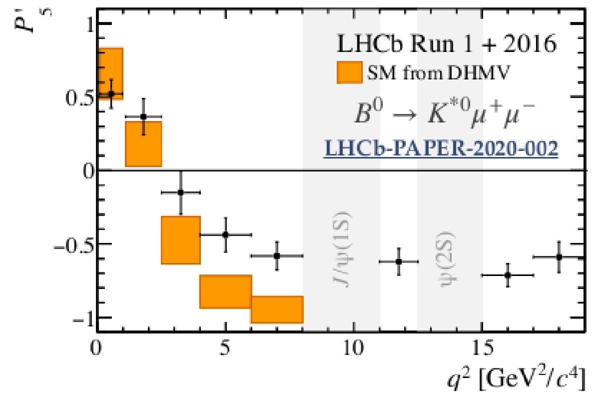
Enhancing or suppressing decay rates

Modifying the angular distributions

Introducing new source of CP violations

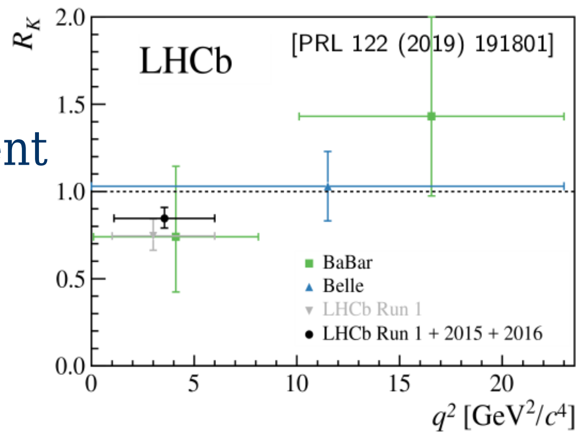
Recent anomalies in rare decays

- Several deviations in differential branching ratios, angular and CP observables have already seen in $b \to s l^+ l^-$
  → See David Gerick's talk



Phys. Rev. Lett. 125, 011802 (2020)

Consistent with SM at 2.5σ



- Clean tests provided by lepton flavour universality measurements
  → Carla Marin's talk

But..

- Most of the results are dominated by the statistical uncertainties
  - Update the previous measurements with a larger dataset
  - Look for complementary observables → **baryonic $b \to s l^+ l^-$ transitions**

Rare baryonic decays are sensitive to different spin-structure BSM effects

Copious amount of Λ_b at LHCb (~ 40% of B mesons produced)

Latest baryonic results from LHCb

- Test of lepton universality with $\Lambda_b \rightarrow pKl^+l^-$ decays (JHEP 05 (2020) 040)

- First observation of the radiative decay $\Lambda_b \rightarrow \Lambda\gamma$ (Phys. Rev. Lett. 123 (2019) 031801)$^-$

- Angular moments of the decay $\Lambda_b \rightarrow \Lambda\mu^+\mu^-$ at low hadronic recoil (JHEP 09 (2018) 146)

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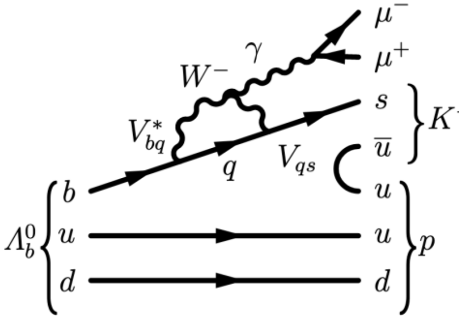
Measurement of R_{pK}

- Test of lepton universality with $\Lambda_b \rightarrow pKl^+l^-$ decays
  - Complementary to $R_{K(*)}$ because of non-zero spin

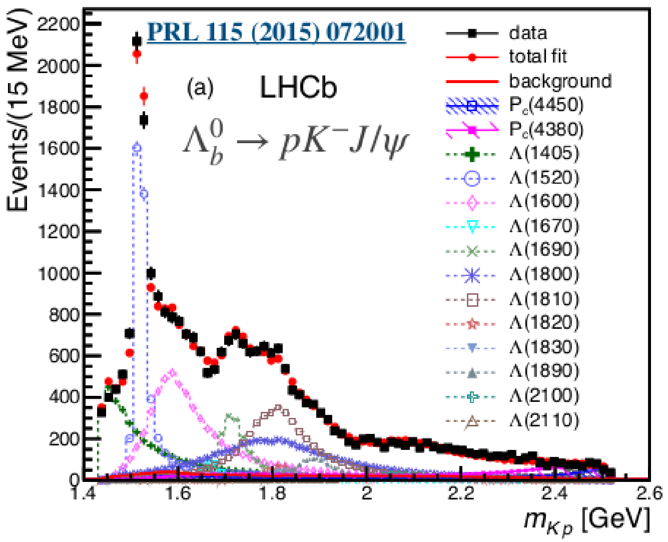


- The ratio is expected to be close to unity in SM [Phys.Lett. B800 (2020) 135080]
- Dataset: Run 1 and 2016 data (4.7 fb^{-1})

- The measurement is performed as a double ratio of

$$R_{pK}^{-1} = \frac{\mathcal{B}(\Lambda_b^0 \to pK^- e^+ e^-)}{\mathcal{B}(\Lambda_b^0 \to pK^- J/\psi(\to e^+ e^-))} \Bigg/ \frac{\mathcal{B}(\Lambda_b^0 \to pK^- \mu^+ \mu^-)}{\mathcal{B}(\Lambda_b^0 \to pK^- J/\psi(\to \mu^+ \mu^-))}$$

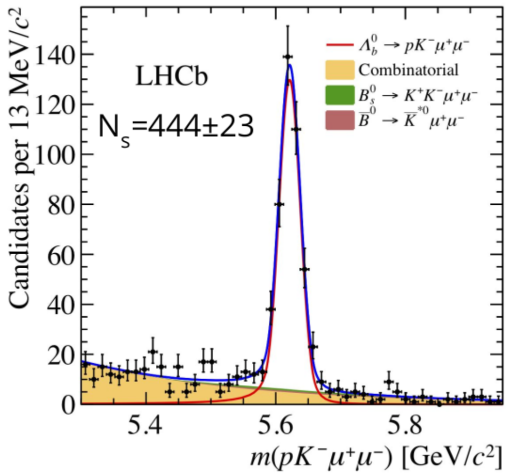
- Region of interest:
  - far from charmonium and dimuon threshold
    → $0.1 < q^2 < 6$ GeV^2/c^4
  - multiple overlapping Λ^* resonances of different J
    → m(pK) < 2.6 GeV/c^2

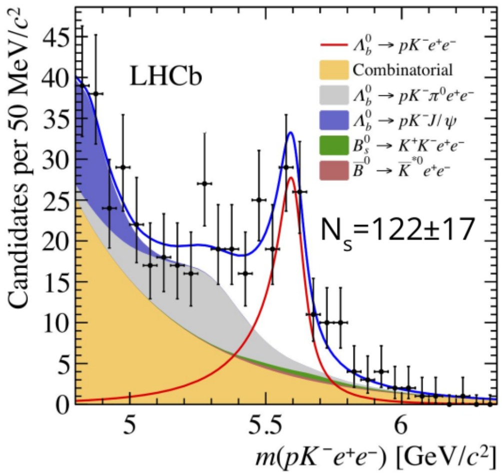


- Extremely challenging due to significant differences in the way μ and e interact with the detector:
  - bremsstrahlung
  - trigger

Measurement of R_{pK}

- Dominant backgrounds:
  - Random track combiations → MVA
  - Hadron misidentifications such as $B_s \to KKl^+l^-$
  - Partially reconstructed backgrounds
- Two separated fits have been performed to resonant and non resonant channels
- Simultaneous fit to electron and muon mode, across various data-taking periods for both trigger categories
- The main systematical uncertainties due to partially reconstructed background shape in $\Lambda_b \to pKe^+e^-$ ($\Lambda_b \to pK^*e^+e$, $\Lambda_b \to pK\pi^0e^+e^-$)





$$R_{pK}\big|_{0.1<q^2<6\,\mathrm{GeV}^2/c^4} = 0.86^{+0.14}_{-0.11} \pm 0.05$$

- Compatible with SM and previous R measurements

→ see Carla Marin's talk

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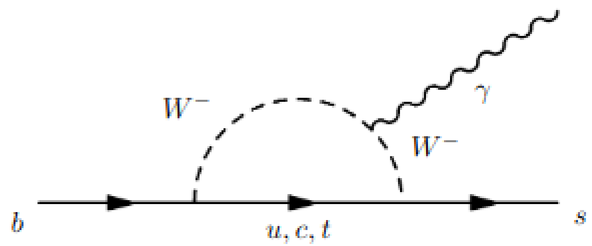
Search for $\Lambda_b \to \Lambda\gamma$

- The radiative decay $\Lambda_b \to \Lambda\gamma$ proceeds via flavour- changing neutral current transition
  - Forbidden at tree level in the SM
    → sensitive to new particles entering in the loop



- The radiative b-baryon decays have never been observed and offer an unique benchmark to measure the photon polarization due to non zero spin of the initial and final state particles

- The branching ratio in the SM: 10^{-7} – 10^{-5}, large uncertainties due to lack of form factors measurements

- CDF set the best branching ratio limits: $B(\Lambda_b \to \Lambda\gamma) < 1.9 \times 10^{-3}$ @ 90% CL
  [Phys.Rev D66 (2002) 112002]
  → large room for improvement

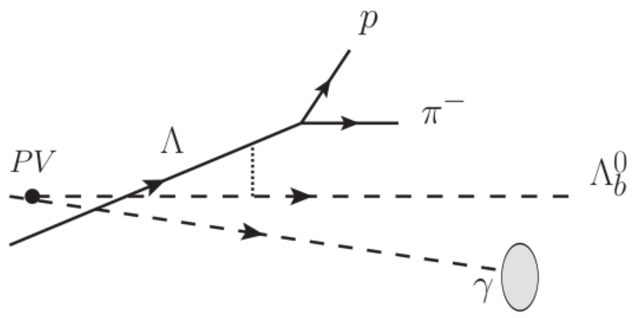
Search for $\Lambda_b \to \Lambda\gamma$

- The $\Lambda_b \to \Lambda\gamma$ decay is experimentally challenging to reconstruct

- The Λ_b vertex cannot be determined directly due to:
  - The long lifetime of the weakly decaying Λ baryon

  - Unknown photon direction since it is reconstructed as a cluster in the calorimeter

    → is not possible to use the displacement with respect to the primary vertex to separate background coming directly from the pp collisions.



- Potential contamination from neutral pions reconstructed as a single cluster in the calorimeter is suppressed by exploiting neutral PID tool [LHCb-PUB-2015-016]

- The dominant background is formed by real baryons and random photon
- Other important background $\Lambda_b \to \Lambda\eta$

Search for $\Lambda_b \to \Lambda\gamma$

- The yields are obtained, using the well-measured $B \to K^*\gamma$ as normalization mode:

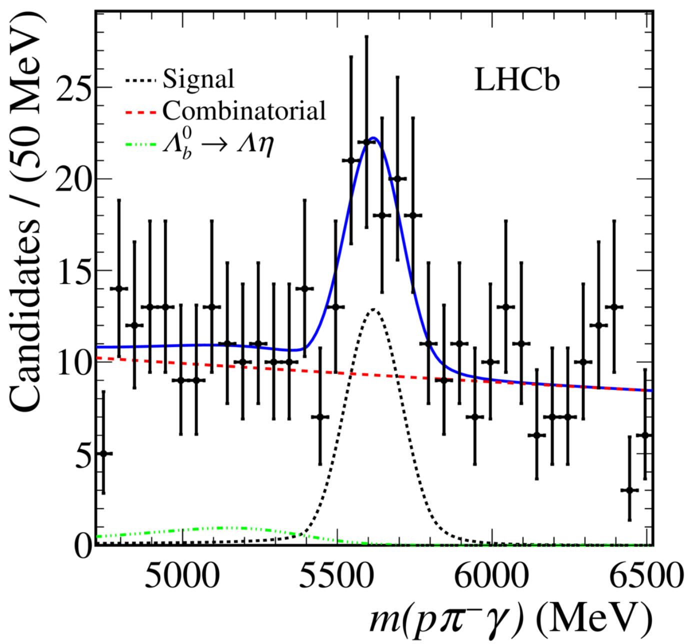
$$\frac{N(\Lambda_b^0 \to \Lambda\gamma)}{N(B^0 \to K^{*0}\gamma)} = \frac{f_{\Lambda_b^0}}{f_{B^0}} \times \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda\gamma)}{\mathcal{B}(B^0 \to K^{*0}\gamma)} \times \frac{\mathcal{B}(\Lambda \to p\pi^-)}{\mathcal{B}(K^{*0} \to K^+\pi^-)} \times \frac{\epsilon(\Lambda_b^0 \to \Lambda\gamma)}{\epsilon(B^0 \to K^{*0}\gamma)}$$

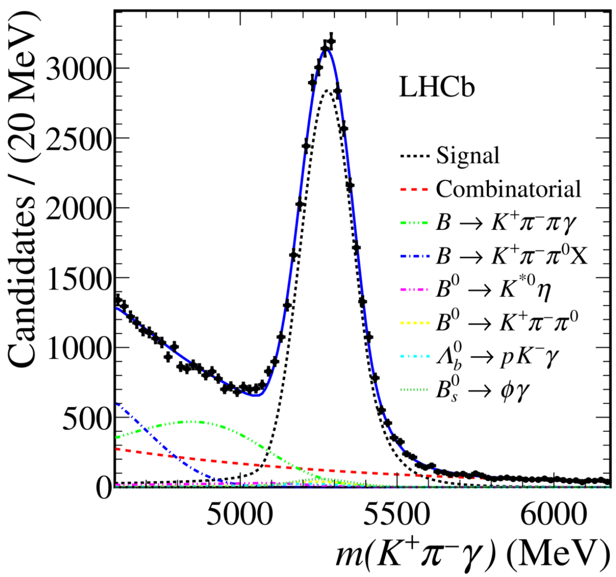
hadronization fractions from LHCb measurement [Phys.Rev. D100 (2019) no.3, 031102]

from PDG

Efficiencies from simulation and calibrations samples

- A simultaneous extended maximum likelihood fit has been performed





- First observation of $\Lambda_b \to \Lambda\gamma$
- Branching fraction measurement:

$$\mathcal{B}(\Lambda_b^0 \to \Lambda\gamma) = (7.1 \pm 1.5 \pm 0.6 \pm 0.7) \times 10^{-6}$$

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Angular analysis of $\Lambda_b \rightarrow \Lambda\mu^+\mu^-$

JHEP 09 (2018) 146

- In the extensions of the SM the angular distributions of the decays can be modified significantly
- Anomalies already seen in $B \rightarrow K^*\mu^+\mu^-$
- Differences with respect B meson decays
  - Λ_b is a spin half and can be produced polarized
  - the transition involves a diquark system as a spectator
  - Λ decays weakly in observables related to the hadronic part of the decay

  → important additional test of the SM predictions

- This is the first measurement of the full basis of angular observables for this decays
- Focused to low hadronic recoil, $15 < q^2 < 20$ Gev^2/c^4
- Dataset: 2011-2016 (5fb^{-1})

Angular analysis of $\Lambda_b \to \Lambda\mu^+\mu^-$

JHEP 09 (2018) 146

- The analysis exploits the method of moments [JHEP 11 (2017) 138]

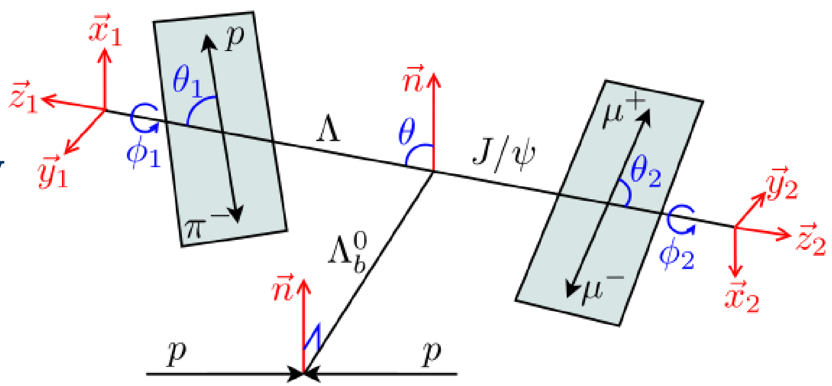
- The full angular distributions can be described as a sum of 34 terms:

$$\frac{\mathrm{d}^5\Gamma}{\mathrm{d}\vec{\Omega}} = \frac{3}{32\pi^2}\sum_i^{34} K_i f_i(\vec{\Omega})$$

Coefficients which depend on the underlying short-distance physics and on the form factors

Angular functions

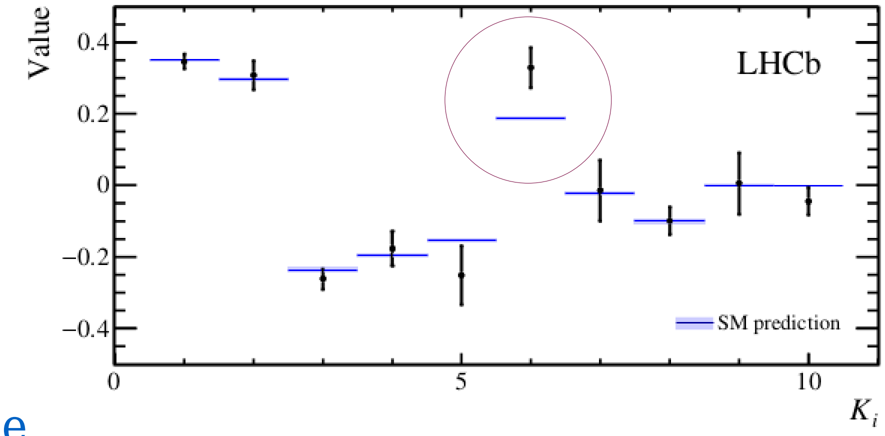
- The angular distributions can be described by
  - 5 angles θ, θ_1,θ_2, ϕ_1,ϕ_2
  - $q^2 = m_{ll}^2$



Angular analysis of $\Lambda_b \to \Lambda\mu^+\mu^-$

JHEP 09 (2018) 146

- The parameters K are determined using the method of moments
- Background is subtracted using weights obtained by fitting the $p\pi\mu^+\mu$ distributions
- The trigger, reconstruction and selection distort the measured angular distribution
  → correction to the angular efficiency using $\Lambda_b \to \Lambda\mu^+\mu$ simulated events
  - The angular efficiency model is cross-checked using $B \to J/\psi K_s$ and $\Lambda_b \to \Lambda J/\psi$ decays in data
- All parameters resulted compatible with the SM predictions
  - The largest discrepancy is seen in K_6: 2.6σ from SM predictions
  - $K_{11\text{-}34}$ compatible with no initial Λ_b polarization



- The K observables can be combined to determine the angular asymmetries

$$A_{\mathrm{FB}}^{\ell} = \tfrac{3}{2}K_3 = -0.39 \pm 0.04 \pm 0.01$$
$$A_{\mathrm{FB}}^{h} = K_4 + \tfrac{1}{2}K_5 = -0.30 \pm 0.05 \pm 0.02$$
$$A_{\mathrm{FB}}^{\ell h} = \tfrac{3}{4}K_6 = +0.25 \pm 0.04 \pm 0.01$$

agreement with SM

2.6σ from SM predictions

Conclusion

- Rare decays are useful tools to search for New Physics beyond the SM
- Hints of tension with the SM predictions are observed in the $b \to s l^+ l^-$ transitions in differential branching ratios, angular observables and in the tests of lepton flavour universality
- Rare baryonic decays are sensitive to different spin-structure BSM effects with respect to the meson decays
  → complementary measurements are necessary
- Several measurement are dominated by the statistical uncertainty

  → update of the existing analysis to confirm the results

  → new measurements

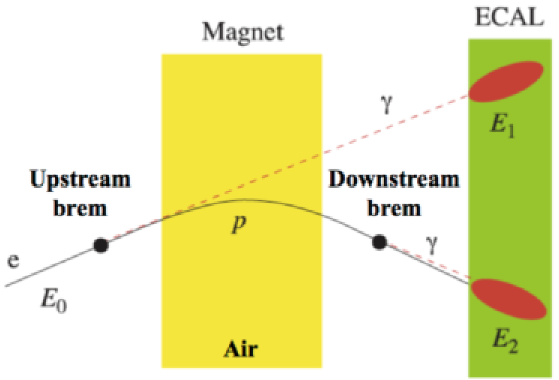
Thank you for your attention!

Backup

- Electron reconstruction is more difficult than muon due to bremsstrahlung.

- The electrons emit a large amount of bremsstrahlung that results in a degraded B momentum and mass resolution.

- Recovery momentum procedure: extrapolation of the electron track upstream and addition of the bremsstrahlung calorimeter cluster to electron momentum.



- Due to higher occupancy of the calorimeters compared to the muon stations, hardware trigger thresholds on the electron E_T are higher than on the muon p_T

  (L0 Muon, p_T >1.5,1.8 GeV)

  → partial loss of electron signal

  → to partially mitigate this effect 2 exclusive trigger categories are considered: events triggered independent of the signal decay, and events triggered by the signal decay