Rare, radiative and electroweak penguin decays of heavy flavour hadrons at LHCb

Clara Remón Alepuz, on behalf of the LHCb collaboration

Rencontres Moriond QCD

La Thuile, March 2019
Outline

- Introduction: New physic searches in rare-$b$ decays
- Experimental status (excluding LFUV*)
- $b \rightarrow s\gamma$ transitions:
  - **NEW!!** First observation of the rare radiative $\Lambda_b \rightarrow \Lambda\gamma$ decay
    LHCb-PAPER-2019-010
  - **NEW!!** Measurement of mixing-induced $CP$-violating observables in $B_s^0 \rightarrow \phi\gamma$

* LFUV related talks will be presented this afternoon, see talk by Rolf Oldeman with new results!
Rare-$b$ decays

Flavour Changing Neutral Currents (FCNC) only occur via loop diagrams in the SM. **New heavy particles** can enter the loop inducing quantum effects

\[ b \to s\gamma \]

\[ b \to \ell^+\ell^- \]

\[ b \to s\ell^+\ell^- \]

**Indirect searches can probe New Physics much larger scales**
Rare-\(b\) decays

Model-independent description: \( \mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha}{4\pi} \sum_i \{C_i O_i + C_i' O_i'\} \)

\[ b \to s\gamma \left( C_7^{(\prime)} \right) \]

\[ b \to \ell^+\ell^- \left( C_{10, S, P}^{(\prime)} \right) \]

\[ b \to s\ell^+\ell^- \left( C_{7, 9, 10}^{(\prime)} \right) \]

NEW!!

\( B_s^0 \to \phi\gamma \)
\( \Lambda_b \to \Lambda\gamma \)

In agreement with SM

\[ B_{(s)} \to \mu^+\mu^- \]
\[ B_{(s)} \to \tau^+\tau^- \]

Several deviations

\[ B \to K^*\mu\mu \left( P_5^i \right), \ldots \]
\[ \Lambda_b \to \Lambda\mu\mu \text{ (BR, angular)} \]

PRL. 118, 191801 (2017)
PRL. 118, 251802 (2017)
Experimental status

Several deviations observed in $b \rightarrow s \ell \ell$ measurements (BR’s and angular analysis)

Global fit

- Global fits show that anomalies in $b \rightarrow s \ell \ell$ can be explained by NP contributions in $C_9$ or both $C_9$ and $C_{10}$

- LFUV results point in the same (up to $5\sigma$) see talk by Rolf Oldeman with new results!

- Possible interpretations:
  Underestimated hadronic uncertainties (while do not explain LFUV)
  NP contributions coming from $Z'$, lepto-quarks ...
Radiative decays

$b \rightarrow s\gamma$

► **NEW!!** First observation of the rare radiative $\Lambda_b \rightarrow \Lambda\gamma$ decay

► **NEW!!** Measurement of mixing-induced $CP$-violating observables in $B_s^0 \rightarrow \phi\gamma$
Radiative $b \rightarrow s\gamma$ decays

- Due to the chiral structure of $W$ bosons, in the SM the photon polarization is predominantly left-handed, with a small right-handed component:

$$\frac{C'_7}{C_7} \sim O\left(\frac{m_s}{m_b}\right)$$

- In some models (like LRSM), $|A_R/A_L|$ up to 1/2  Fu-Sheng Yu et al., JHEP12(2013)102
First observation of the rare radiative $\Lambda_b \to \Lambda\gamma$ decay

NEW!!*

* Presented last week in Moriond EW
Search for $\Lambda_b \rightarrow \Lambda \gamma$

Large room for improvement in $\mathcal{B}(\Lambda_b \rightarrow \Lambda \gamma)$:

- **SM prediction:** $10^{-7} - 10^{-5}$
- **Best limit from CDF:** $< 1.9 \times 10^{-3}$ (95% CL)

- If observed, it will open the possibility for **photon polarization** measurement in $b$-baryon decays through angular analysis
  

- Reconstruction very challenging:
  - No $\Lambda_b^0$ decay vertex
  - Crucial signal/background separation
    - High performance BDT (XGBoost)
  - $B^0 \rightarrow K^{*0} \gamma$ used as normalization channel
Search for $\Lambda_b \rightarrow \Lambda \gamma$

- Using 2016 data ($1.7 \text{ fb}^{-1}$)
- **First observation** of $\Lambda_b \rightarrow \Lambda \gamma$ (5.6 significance)

\[
\mathcal{B}(\Lambda_b \rightarrow \Lambda \gamma) = (7.1 \pm 1.5 \pm 0.7 \pm 0.6) \times 10^{-6}
\]

- Branching fraction measurement within range of SM predictions
- Main systematic comes from the limited knowledge of the ratio of hadronization fractions $f_{\Lambda_b^0}/f_{B^0}$
Photon polarization in $B_s^0 \rightarrow \phi\gamma$

- Mixing induced interference gives access to the photon polarization through the time evolution of $B_s^0 \rightarrow \phi\gamma$

$$\Gamma(t) \propto e^{-\Gamma_s t} \left[ \cosh \left( \frac{\Delta \Gamma_s t}{2} \right) - A_{\phi\gamma}^\Delta \sinh \left( \frac{\Delta \Gamma_s t}{2} \right) \pm C_{\phi\gamma} \cos (\Delta m_s t) \right]$$

- $A_{\phi\gamma}^\Delta$ and $S_{\phi\gamma}$ are sensitive to photon polarization (and weak phases), while $C_{\phi\gamma}$ is related to direct CP violation
- SM predictions close to zero
- $A_{\phi\gamma}^\Delta$ measured at LHCb with Run I data

$$A_{\phi\gamma}^\Delta = -0.98^{+0.46}_{-0.52} +0.23_{-0.20}$$


[PRL 118(2017)2,021801]
Photon polarization in \( B_s^0 \rightarrow \phi \gamma \)

- Mixing induced interference gives access to the photon polarization through the time evolution of \( B_s^0 \rightarrow \phi \gamma \)

\[
\Gamma(t) \propto e^{-\Gamma_s t} \left[ \cosh \left( \frac{\Delta \Gamma_s t}{2} \right) - A_{\phi \gamma}^\Delta \sinh \left( \frac{\Delta \Gamma_s t}{2} \right) \pm C_{\phi \gamma} \cos (\Delta m_s t) \right] \\
\pm S_{\phi \gamma} \sin (\Delta m_s t)
\]

- \( A_{\phi \gamma}^\Delta \) and \( S_{\phi \gamma} \) are sensitive to photon polarization (and weak phases), while \( C_{\phi \gamma} \) is related to direct CP violation

- SM predictions close to zero \([\text{PLB 664(2008)174-179}]\)

- NEW!! Using the flavour information of the initial \( B_s \) meson we can also measure \( C_{\phi \gamma} \) and \( S_{\phi \gamma} \) \([\text{LHCb-PAPER-2019-015}]\) (in preparation)

**First measurement** of \( C_{\phi \gamma} \) and \( S_{\phi \gamma} \) in \( B_s \) decays
Measurement of mixing-induced CP-violating observables in $B_s^0 \rightarrow \phi\gamma$

NEW!!
Mass fit

- $B^0_s \rightarrow \phi \gamma$ (signal) and $B^0 \rightarrow K^{*0} \gamma$ (control) decays are reconstructed, with two opposite sign hadrons ($\phi \rightarrow K^+ K^-$ and $K^{*0} \rightarrow K^\pm \pi^\pm$) and a high-$E_T$ photon in the final state.

- Background subtracted with sPlot, fitting the reconstructed B mass:
  - **Signal**: double-sided Crystal Ball
  - **Combinatorial**: First-order polynomial
  - **Partially reconstructed**: ARGUS convolved with a Gaussian

- 5300 signal yield (Run I)
- 32 000 signal yield (Run I)

![Graphs showing mass fit](image_url)
Proper-time fit

- Simultaneous unbinned ML fit to $B^0_s \rightarrow \phi \gamma$ and $B^0 \rightarrow K^{*0} \gamma$ channels.

$$\Gamma_{B^0_s \rightarrow \phi \gamma}(t') = \Gamma(t', q|\omega) \otimes \{A(t_i)R(t, t' |\sigma_t)\}$$

Per-candidate $\sigma_t$ and flavor-tagging information $(q, \omega)$ are used

$B_s, \bar{B}_s$ and untagged

$$S_{\phi\gamma} = 0.43 \pm 0.30 \pm 0.11,$$

$$C_{\phi\gamma} = 0.11 \pm 0.29 \pm 0.11,$$

$$A_{\phi\gamma}^\Delta = -0.67^{+0.37}_{-0.41} \pm 0.17$$

Compatible with the SM at 1.3, 0.3 and 1.7 $\sigma$
$S_{\text{CP}}$ and $C_{\text{CP}}$ measurements in $b \rightarrow s\gamma$ transitions

- Measurement competitive with the previous measurements in $B$-factories.
- First measurement in $B_s$ system
\( A_{\phi\gamma} \) and \( S_{\phi\gamma} \) give complementary constraints in the \( C'_7 \) complex plane.

\[
A_{\phi\gamma} \overset{\Delta}{\sim} \frac{\text{Re}(e^{-i\phi_s C_7 C'_7})}{|C_7|^2+|C'_7|^2}
\]

\[
S_{\phi\gamma} \overset{\Delta}{\sim} \frac{\text{Im}(e^{-i\phi_s C_7 C'_7})}{|C_7|^2+|C'_7|^2}
\]
Summary

Rare b-decays occur via FCNC allowing to probe large energy scales through indirect measurements

- Interesting pattern of deviations has emerged in $b \to s\ell\ell$. Consistent with the LFUV anomalies, both pointing in the same direction to NP

Latest results in LHCb (involving $b \to s\gamma$):

- First observation of the rare radiative $\Lambda_b \to \Lambda\gamma$, opening the possibility of photon polarization measurements in $b$-baryons
- Time-dependent analysis of $B_s^0 \to \phi\gamma$ gives constraints on $\text{Re}(C'_7)$ and $\text{Im}(C'_7)$. This is the first measurement of $C_{CP}$ and $S_{CP}$ in $B_s^0$ decays

Run 2 analysis ongoing stay tuned!