Radiative decays at LHCb

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M. Chefdeville, LAPP, Annecy

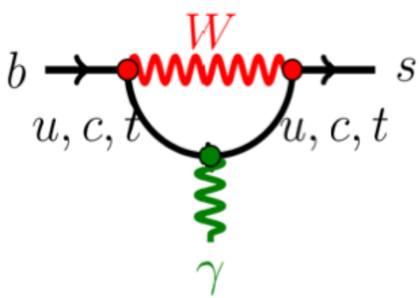
Overview

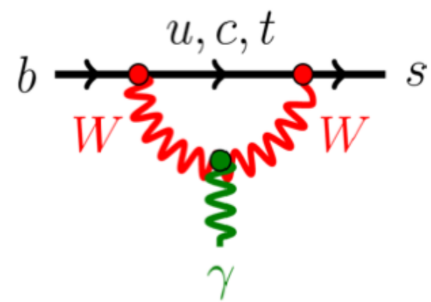
- Introduction
  - RAD penguins, key observables, LHCb program
- Past-present-future
  - Published analysis
  - New baryon results
  - On-going analysis
- Outlook

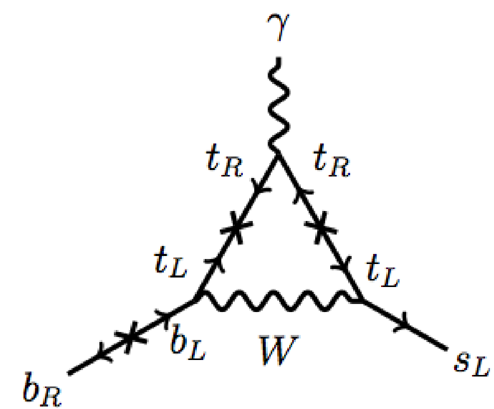
Radiative b → (s,d)γ transitions

- Change quark chirality: **$b_R \to s_L \gamma_L$** (left-handed amplitude) or **$b_L \to s_R \gamma_R$** (RH amp.)
  - As a **FCNC**, proceeds through a loop (W & Up-type quarks) and thus CKM-suppressed
  - **Chirality flip** required on external quark lines ($SU(2)_L$) and internal lines (avoid GIM cancellation)

    → **mass insertions** favor flip on b-line: **γ mostly LH** in b → qγ, **RH amplitude suppressed by m_q/m_b**







- **Effective Hamiltonian**
  - Hadronic final states (**Vγ**) → EM dipole operators **$O_{7(L,R)}$**
  - Non-had. or virtual-γ final-states (**$l^+l^-\gamma$, Vee**) → also test axial-vector and vector operators **$O_{9,10}$**

$$\mathcal{H}_{\rm rad} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* (C_{7R}\mathcal{O}_{7R} + C_{7L}\mathcal{O}_{7L})$$

$$\mathcal{O}_{7L,R} = \frac{e}{16\pi^2} m_b \bar{s} \sigma_{\mu\nu} \frac{1 \pm \gamma_5}{2} b F^{\mu\nu}$$

$$\lambda_\gamma^{(i)} = \frac{|c_R^{(i)}|^2 - |c_L^{(i)}|^2}{|c_R^{(i)}|^2 + |c_L^{(i)}|^2}$$

- **New physics in loop affects the transition dynamics (BR, A_{CP}, A_I, λ)**

Observables

- Branching ratios
  - Too uncertain for NP searches (form factors <V|Q_j|B>)
  - Ratio can be interesting *Ali, Pecjak, Greub 2008*
- Isospin asymmetries *Ball et al. 2007*
  - Photon from different spectator quarks (B^0,B^+)
  - Sensitive to long-distance topologies (WA, quark-loops)
- CP asymmetries
  - Small in $b \to s$ (0.5%), larger in $b \to d$
- Photon polarisation
  - TD-CPV *Atwood, Gronau, Soni 1997*

    S-term should be zero $\to$ null-test of SM

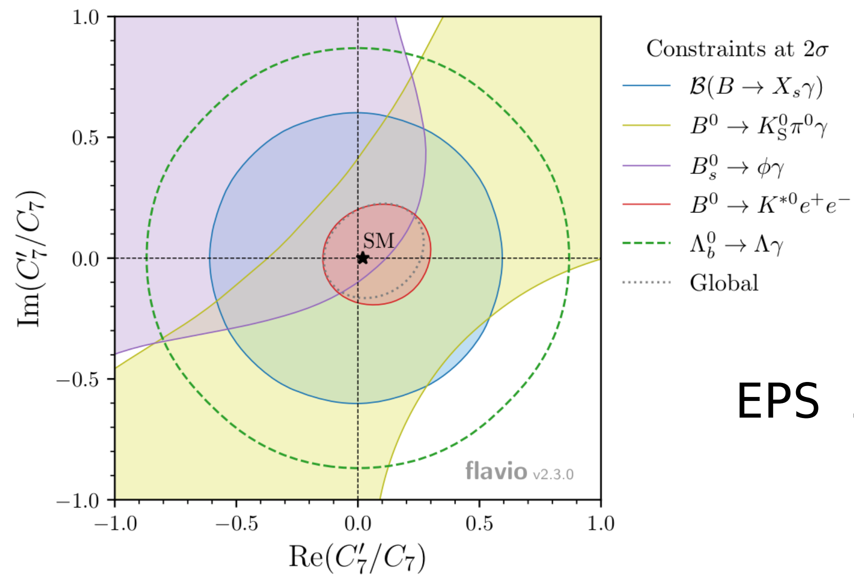
    $B^0 \to K^{*0}[K_S\pi^0]\gamma$ or $K_s\pi\pi\gamma$, $B_s \to \Phi\gamma$
  - Angular/Amplitude analysis

    $B^0 \to K^*ee$ @ low-q^2, $\Lambda_b \to \Lambda^0\gamma$, $B^+ \to K\pi\pi\gamma$

    Gronau, Grossman, Pirjol, Ryd, 2002
- Constraints on CKM angle γ
  - Ratio $|V_{td}/V_{ts}|^2$ from e.g. $K^{*0}\gamma$ VS $\rho^0\gamma$

M. Matsumori, A. I. Sanda, Y.-Y. Keum, 2005

$$Br(B^0 \to K^{*0}\gamma) = (5.8 \pm 2.9) \times 10^{-5}, \quad (97)$$
$$Br(B^\pm \to K^{*\pm}\gamma) = (6.0 \pm 3.0) \times 10^{-5}. \quad (98)$$
$$A_{CP}(B^0 \to K^{*0}\gamma) = -(6.1 \pm 4.6) \times 10^{-3}, \quad (105)$$
$$A_{CP}(B^\pm \to K^{*\pm}\gamma) = -(5.7 \pm 4.3) \times 10^{-3}. \quad (106)$$
$$\Delta_{0+} = +(2.7 \pm 0.8) \times 10^{-2} \quad (107)$$



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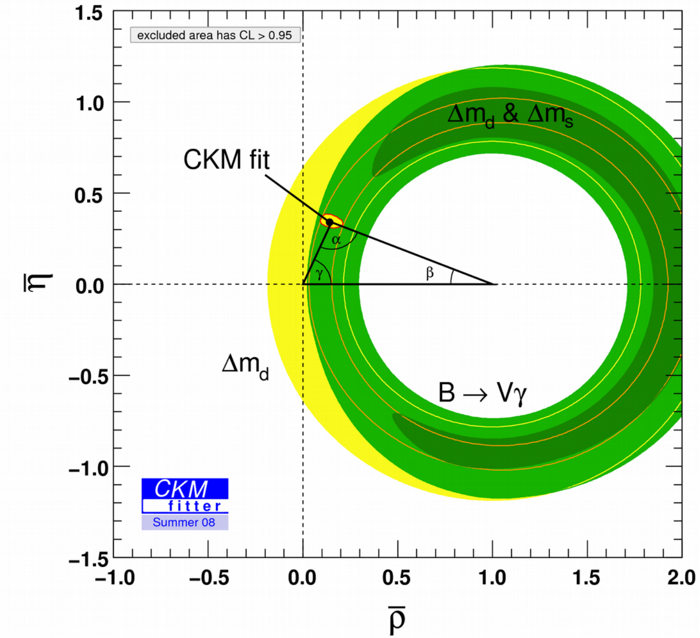
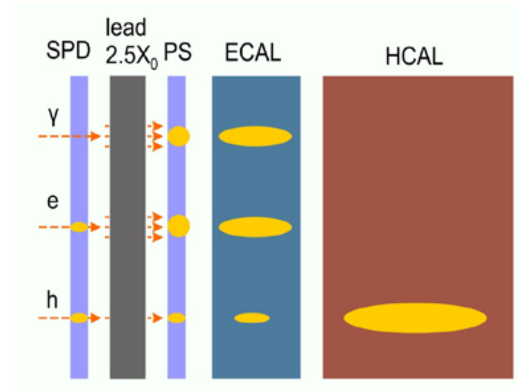


CKM fitter 2008

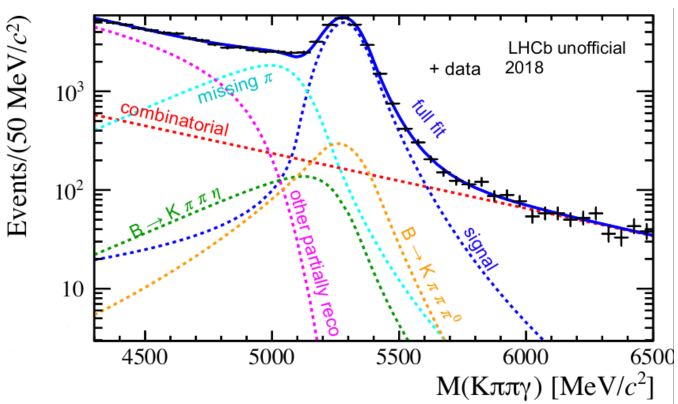
Radiatives at LHCb

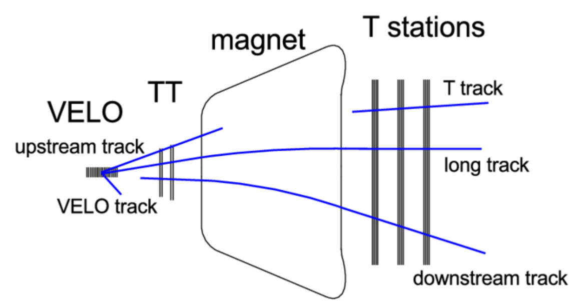
- Hadronic environment
  - Several b-species produced (B_d, B_u, B_s, Λ_b, Ξ_b, Ω_b…)
  - Large combinatorics (tight P_T cuts (2.5 GeV/c))
- Calorimeter system = SPD + PRS + ECAL + HCAL
  - Shashlik Pb-Scintillators, $10\%/\sqrt{E[\mathrm{GeV}]} + 1\%$
  - Folded with position resolution, yields $\sigma(m_B) \approx 90$ MeV

    $\rightarrow$ careful modeling of partially reco'ed &peaking bkgs

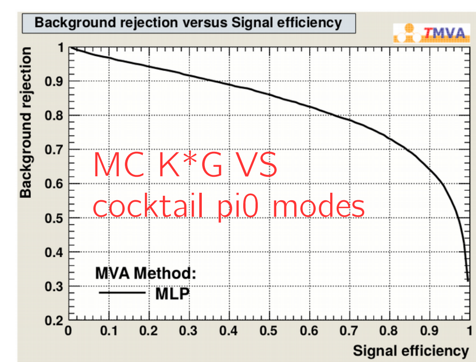


- Photons converting before the magnet can be reco'ed as an e^+e^- pair:
  5-10% of calo photon yield but $\sigma(m_B)$ = 30-50 MeV (depending on e-track category)
- Particle ID tools to mitigate e.g. pi0 reco'ed as photons from charmless B decays





LHCb-PUB-2015-016



Physics coverage & published analysis

- Semi-inclusive HLT & offline strategy
  + exclusive selections for (baryons, $\gamma\gamma$, $l^+l^-\gamma$)
  $\rightarrow$ wide shopping list of promising channels

- **Radiative stripping lines based on Long noPID pion(s) + gamma**
  - (h^+h^-) $+\gamma$: covering $K^*\gamma$, $\phi\gamma$, $\rho\gamma$, $\Lambda^*\gamma$, $K^{**}\gamma$, $f'_2\gamma$, …
  - $(h^+h^-h^+)$ $+\gamma$: covering $K_1^+(K\pi\pi)\gamma$, $(\pi\pi\pi)\gamma$, …
  - $(h^+h^-h^+h^-)$ $+\gamma$: covering $VV\gamma$
  - (h^+h^-) $+\pi^0$ $+\gamma$: covering $K_1^0(K^+\pi^-\pi^0)\gamma$, $\omega(\pi^+\pi^-\pi^0)\gamma$, …
  - (h^+h^-) $+K_sK_s$ $+\gamma$: covering $K^{*+}K^{*-}\gamma$, …
  - (h^+h^-) $+K_s$ $+\gamma$: covering $K_1^0(K_s\pi^+\pi^-)\gamma$, $K^{*+}K^-\gamma$, …
  - (h^+) $+K_s$ $+\gamma$: covering $B^+ \to K^{*+}\gamma$, …
  - (h^+h^-) $+\Lambda$ $+\gamma$: covering Λ_b
  - (h^+h^-) $+\Lambda$ $+\gamma$: covering Λ_b
- **Radiative lines based on Long noPID pion(s) + converted gamma (LL+DD)**
  - (h^+h^-) $+\gamma(\to ee)$
  - $(h^+h^-h^+)$ $+\gamma(\to ee)$
- **Exclusive stripping lines** : $\Lambda_b\to\Lambda\gamma$, $\Lambda_b\to\Lambda(\gamma\to ee)$ and control channels
- **Recently added** : trigger path for $Bs\to\gamma\gamma$, b-baryons

- New baryon results

  * Search for $\Xi_b^- \to \Xi^- \gamma$ (Run2 5.4 fb^{-1}), *LHCb-PAPER-2021-017*

  * Photon polarization in $\Lambda_b \to \Lambda\gamma$ decays (Run2 6 fb^{-1}), *LHCb-PAPER-2021-030 (in preparation)*

- Published analysis

---------**BR(KstG)/BR(PhiG)** - Run1 1 fb^{-1}
Phys. Rev. D 85 (2012) 112013
---------------------------------+**ACP(K*G)**
Nucl. Phys. B867 (2013) 1
-----------------**G.Pol in KpipiG** Run1 3 fb^{-1}
Phys. Rev. Lett. 112 (2014) 161801
------------------**AngAna K*ee** Run1 3 fb^{-1}
J. High Energ. Phys. 04 (2015) 64
----------------**Search for JpsiG** Run1 3 fb^{-1}
Phys. Rev. D 92 (2015) 112002
-----------------**TD-CPV PhiG** Run1 3 fb^{-1}
Phys. Rev. Lett. 118 (2017) 021801
Phys. Rev. Lett. 123 (2019) 081802
-------------**Observation L0G** Run2 1.7 fb^{-1}
Phys. Rev. Lett. 123 (2019) 031801
--------------**Ang.Ana. K*ee** Run1+2 9 fb^{-1}
JHEP 12 (2020) 081

Radiative baryon decays

- Nonzero b-baryon spin → direct access to γ-polarisation (*Eur. Phys. J. C 79 (2019) 634*)
- Challenging experimental signatures as secondary vertex is not reconstructed
- First observation of $\Lambda_b \to \Lambda^0\gamma$ (2016 data, *PRL 123 031801 (2019)*)
- Triggered theory work from R. Wang et al. *arxiv:2008.06624*

The angular distribution is:

$$W(\theta_\Lambda, \theta_p) \propto 1 - \alpha_\Lambda P_{\Lambda_b} \cos\theta_p \cos\theta_\Lambda - \alpha_\gamma(\alpha_\Lambda \cos\theta_p - P_{\Lambda_b} \cos\theta_\Lambda) \quad (2)$$

Here, P_{Λ_b} is the initial Λ_b polarization and α_Λ is the Λ^0 weak decay parameter, defined in Table 1.

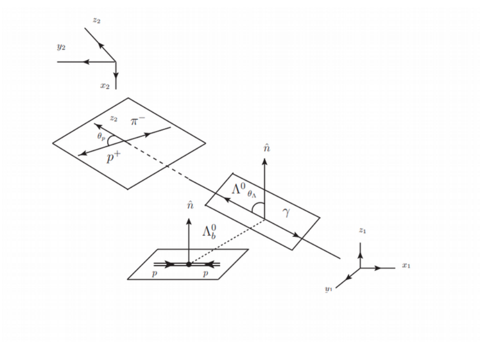


Fig. 1. Schematic view of the $\Lambda_b^0 \to \Lambda^0\gamma$ decay.

Observables	Experimental data [5]	Our SU(3) IRA predictions	Other predictions
$b \to s:$			
$\mathcal{B}(\Lambda_b^0 \to \Lambda\gamma)(\times 10^{-6})$	7.1 ± 1.7	7.1 ± 3.4	7.3 ± 1.5 [69]
$\mathcal{B}(\Lambda_b^0 \to \Sigma^0\gamma)$	···	0	
$\mathcal{B}(\Xi_b^- \to \Xi^-\gamma)(\times 10^{-5})$	···	1.23 ± 0.64	
$\mathcal{B}(\Xi_b^0 \to \Xi^0\gamma)(\times 10^{-5})$	···	1.16 ± 0.60	
$b \to d:$			
$\mathcal{B}(\Lambda_b^0 \to n\gamma)(\times 10^{-7})$	···	5.03 ± 2.67	$3.69^{+3.76}_{-1.95}$, 3.7 [49, 68]
$\mathcal{B}(\Xi_b^0 \to \Lambda^0\gamma)(\times 10^{-8})$	···	9.17 ± 5.10	
$\mathcal{B}(\Xi_b^0 \to \Sigma^0\gamma)(\times 10^{-7})$	···	2.71 ± 1.50	
$\mathcal{B}(\Xi_b^- \to \Sigma^-\gamma)(\times 10^{-7})$	···	5.74 ± 3.21	

Cabibbo-favoured $\mathbf{\Lambda_b \to \Lambda^0\gamma}$ and $\Xi_b^- \to \Xi^-\gamma$

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$$\begin{aligned}W(\eta,\theta_\Lambda,\theta_p,\theta_\Xi) \propto\ & 1+\alpha_\Lambda\alpha_\Xi\cos\theta_p+\alpha_\gamma\alpha_\Xi\cos\theta_\Lambda \\ & +\alpha_\Lambda\alpha_\gamma\cos\theta_p\cos\theta_\Lambda-2\alpha_\Lambda\alpha_\gamma \mathrm{Re}(\mathrm{e}^{\mathrm{i}\eta}\mathrm{z}_\Xi)\sin\theta_\mathrm{p}\sin\theta_\Lambda \\ & -P_{\Xi_b}\alpha_\Xi\cos\theta_\Xi\cos\theta_\Lambda-P_{\Xi_b}\alpha_\gamma\cos\theta_\Xi \qquad (4) \\ & -P_{\Xi_b}\alpha_\Xi\alpha_\Lambda\alpha_\gamma\cos\theta_\Xi\cos\theta_p-P_{\Xi_b}\alpha_\Lambda\cos\theta_\Xi\cos\theta_\Lambda\cos\theta_p \\ & +2\alpha_\Lambda P_{\Xi_b}\mathrm{Re}(\mathrm{e}^{\mathrm{i}\eta}\mathrm{z}_\Xi)\cos\theta_\Xi\sin\theta_\mathrm{p}\sin\theta_\Lambda,\end{aligned}$$

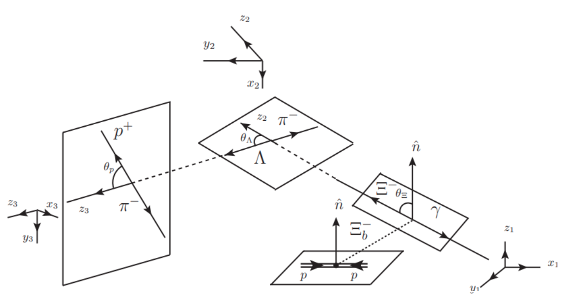

Fig. 2. Schematic view of the $\Xi_b^- \to \Xi^-\gamma$ decay.

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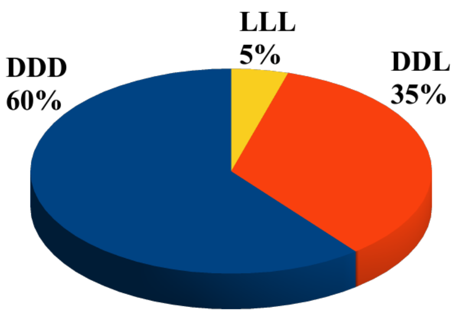
Cabibbo-favoured $\Lambda_b \to \Lambda^0\gamma$ and $\Xi_b^- \to \Xi^-\gamma$

Search for $\Xi_b^- \rightarrow \Xi^- \gamma$ (1/2)

LHCb-PAPER-2021-017

- Uses 5.4 fb^{-1} of Run2 LHCb data
- Strategy:
  - Consider only (**LLL-**)decays contained in VELO (trigger bandwidth)
  - Clean reconstructed Ξ^- and $\Lambda \rightarrow$ mass windows
  - Multi-variate classifier to discriminate signal from bkg
  - Normalisation and control with $\Xi_b^- \rightarrow \Xi^- J/\Psi$



Long track: use Vtx det.
Down track: don't

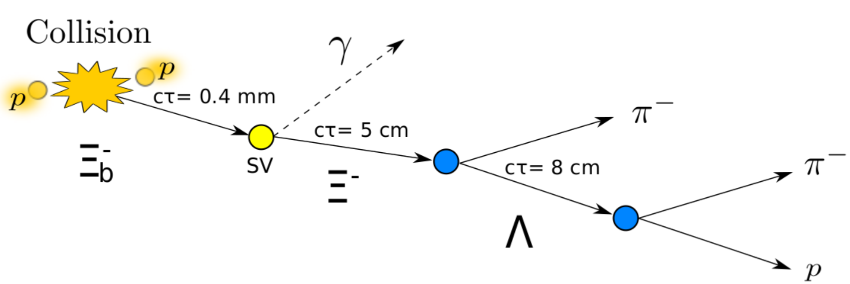
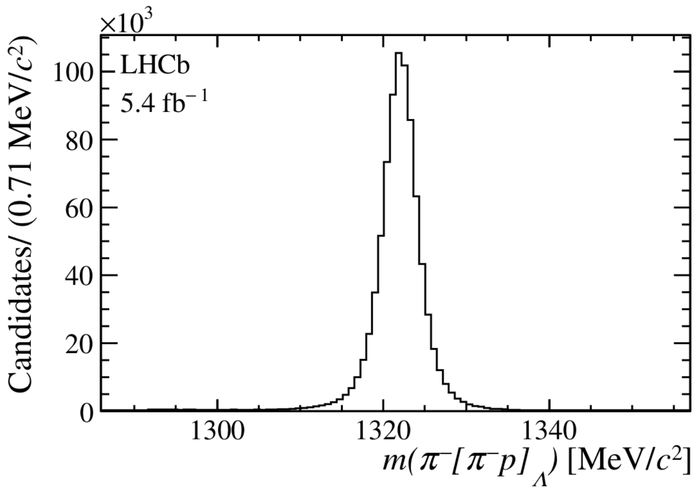


Figure 3: Topology of the $\Xi_b^- \rightarrow \Xi^-\gamma$ decay.



Search for $\Xi_b^- \to \Xi^- \gamma$ (2/2)

LHCb-PAPER-2021-017

- Simultaneous fit to signal and control modes

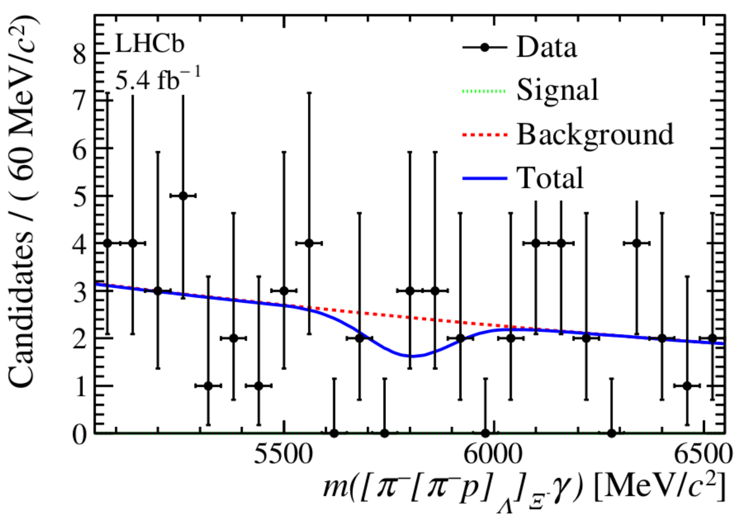
  $N(\Xi^- \gamma) = (-3.6 \pm 3.9)$ and $N(\Xi^- J/\Psi) = (1407 \pm 52)$

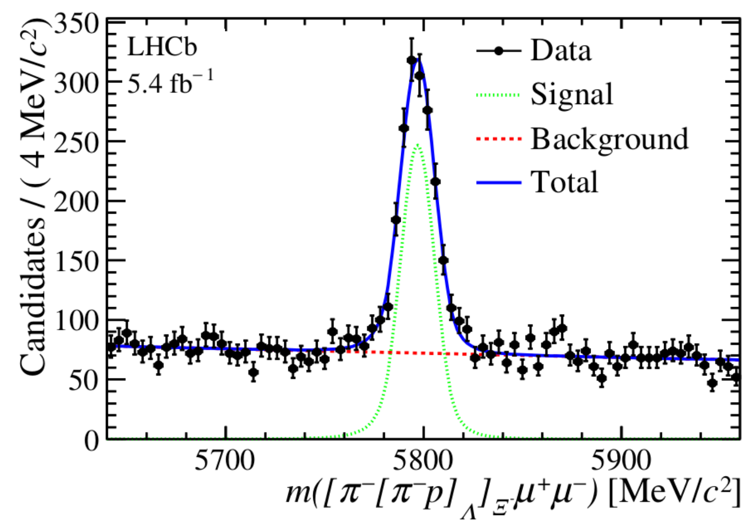
- Limit on branching fraction ($B_{theo} = 1.23 \times 10^{-5}$)

$$\mathcal{B}(\Xi_b^- \to \Xi^- \gamma) < 1.3\,(0.6) \times 10^{-4} \text{ at } 95\%\,(90\%) \text{ CL}$$

  - Dominated by J/Ψ mode BF
  - Largely improved sensitivity in Run3 (trigger & luminosity)

Source	Uncertainty (%)
Mass fit model (signal)	9.1
Mass fit model (background)	7.8
Efficiency ratio	4.6
Hardware trigger	10.0
Simulation/Data agreement	6.0
$\mathcal{B}(\Xi_b^- \to \Xi^- J/\psi)$	45.6
Sum in quadrature	48.7





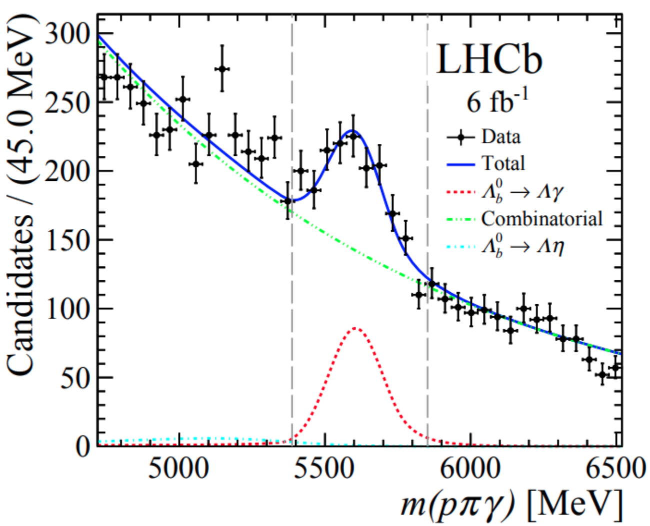
Photon polarization in $\Lambda_b \to \Lambda\gamma$ (1/2)

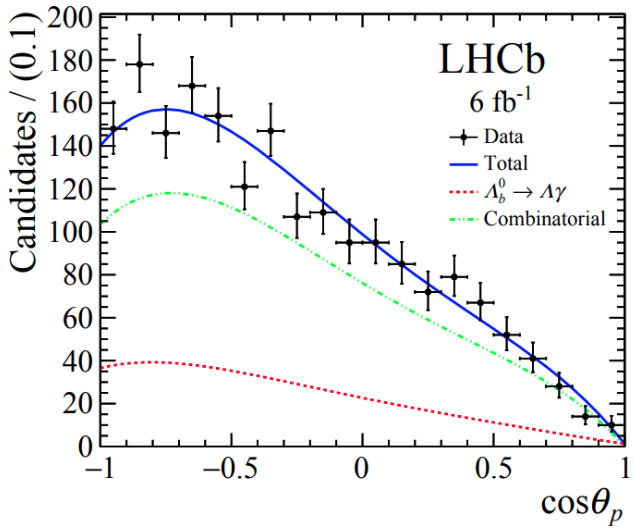
LHCb-PAPER-2021-030
In prep.

- First angular analysis of radiative b-baryon decays (6 fb^{-1} of Run2 data)
  - Follows first observation of (65 ± 13) events in 2016 data (Phys. Rev. Lett. 123 (2019) 031801)
  - $B(\Lambda_b \to \Lambda\gamma) = (7.1 \pm 1.5) \times 10^{-6}$
- Extract γ-polarisation (α_γ) from proton helicity angle θ_p (α_Λ: Λ weak decay parameter, BESIII input)
- Strategy:

  1) **Mass fit** to m(pπγ) → (440 ± 40) events

  2) **Angular fit** in signal region: Signal from simulation (controlled with J/Ψ mode), Bkg from m(pπγ) sidebands





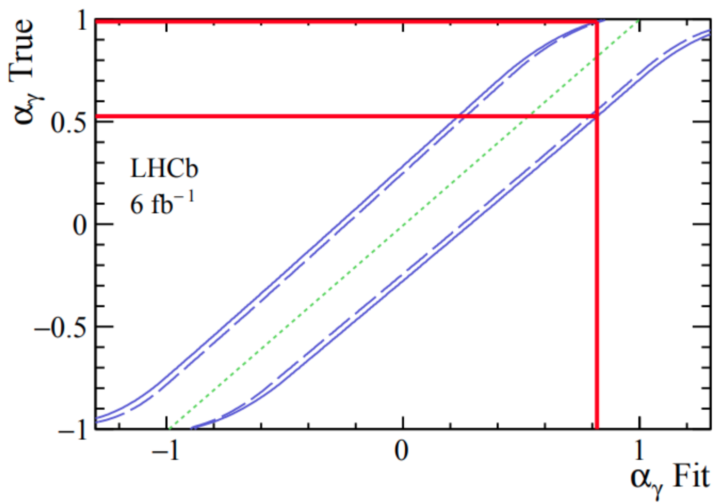
$$\frac{d\Gamma}{d(\cos\theta_p)} \propto 1 - \alpha_\gamma \alpha_\Lambda \cos\theta_p,$$

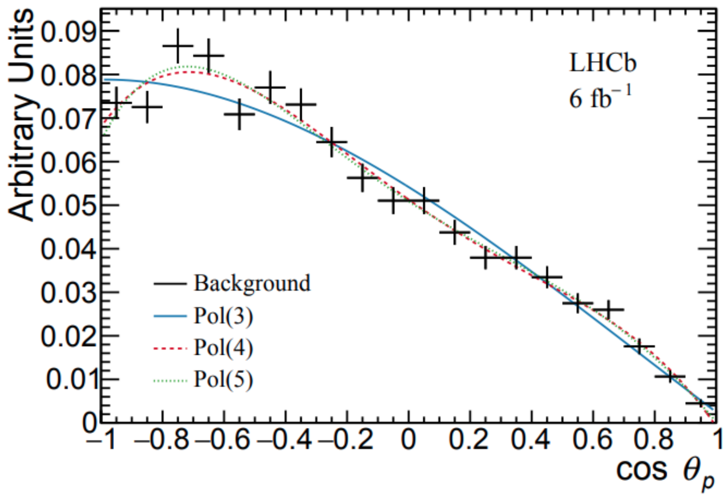
Photon polarization in $\Lambda_b \to \Lambda\gamma$ (2/2)

LHCb-PAPER-2021-030
In prep.

- Results
  - Angular fit yields α_γ = (0.82 ± 0.23)
  - To reflect physical bounds [-1,1] → confidence interval set using the Feldman Cousins technique
    Determine true VS measured value by pseudo-experiments , including stat. and syst. uncertainties
- Uncertainties dominated by statistics (Run3!), main systematics from **bkg modeling of θ_p**
- Slipt sample according to pion charge → polarisation compatible with 1 (i.e. LH) for $\overline{\Lambda}_b$ & Λ_b

$$\alpha_\gamma = 0.82^{+0.17}_{-0.26}\,(\text{stat.})\,^{+0.04}_{-0.13}\,(\text{syst.})$$



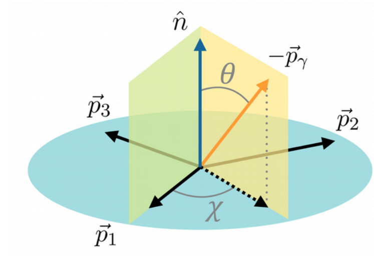


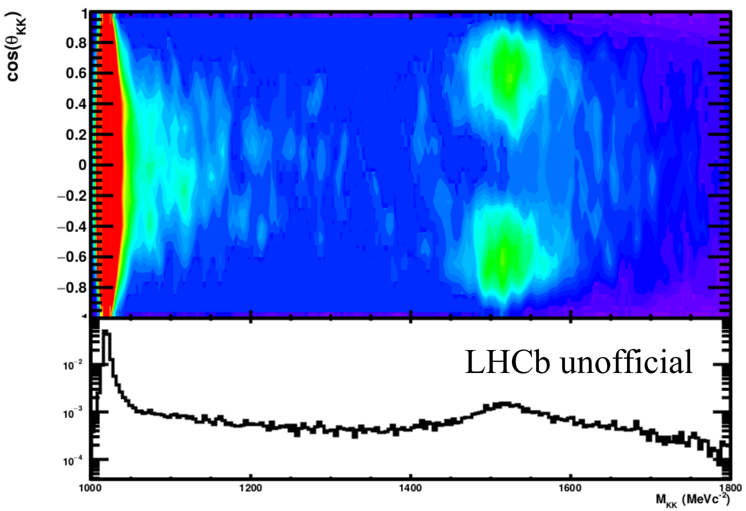
What’s next? (1/2) (on-going analysis on full dataset)

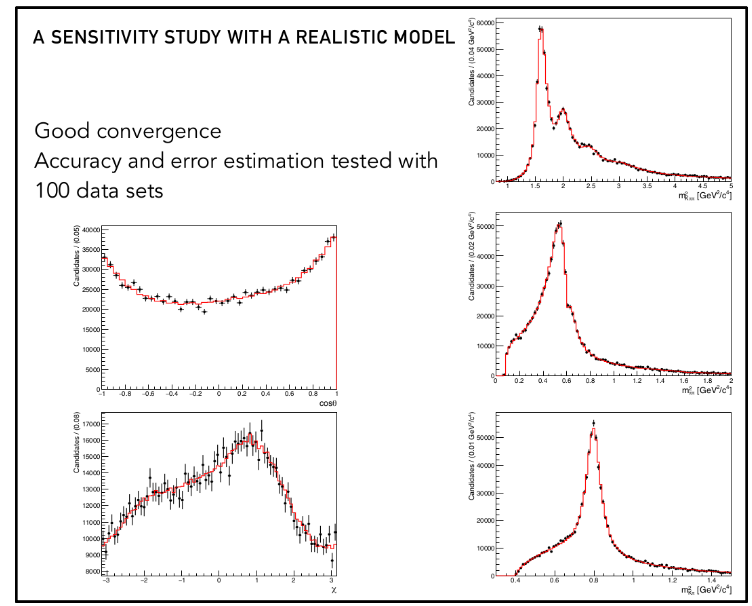
- Amplitude analysis
  - Separate vector and tensor contributions in **$B_s \to KK\gamma$, $B_d \to K\pi\gamma$**

    Better understanding of non-resonant & high-mass contamination in $\varphi\gamma$ and $K^*\gamma$

    Inclusive VS sum of exclusive (predictions in *Ebert et al. 2001*)







LHCb simulation unofficial

  - From up-down asymmetry to γ-polarisation in **$B^+ \to K\pi\pi\gamma$**

    Large sample size $\to \sigma_{stat}(\lambda) = 0.014$ (*Bellée et al, 2019*)

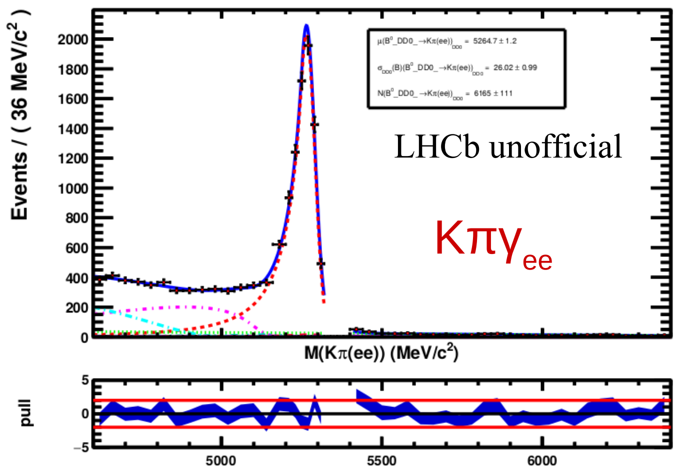
    Precise knowledge of interfering resonances needed (model building)

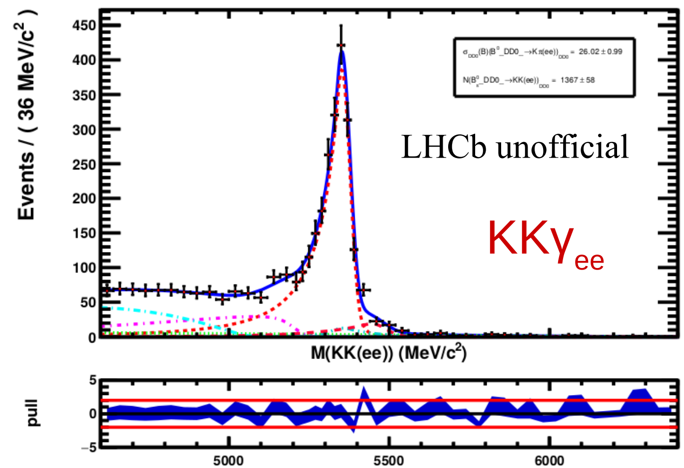
What's next? (2/2) (on-going analysis on full dataset)

- Suppressed modes
  - $B_d \to \rho^0\gamma$ with calorimetric photons (1000 events expected)

    Optimisation in 2 steps: X-feeds ($K\pi$, KK, $p\pi$), combinatorics (BDT)
  - $B_s \to \overline{K}^*\gamma$ with converted photons (140 events expected)

    Signal mass shapes and sensitivity depends on electron track category and if Brem photons were added





- Others: TD-CPV ($K_s\pi\pi\gamma$, Update Run1 result $\varphi\gamma$), BF & asymmetries ($hh\gamma$, K^+K^-, $K^+\pi^-$, $K_S\pi$, pK)

Outlook

- LHCb provides a unique laboratory for precise measurements in radiative decays

  With connections with anomalies in b2sll: fix C_7(') in global fits of $C_{9,10}$, charm-loops contribute to radiative observables, converted photons can be used as cross-checks of RX-electrons etc…

- Several final-states still to be explored (3hγ, 4hγ)

  * γ polarisation in $B^+ \to K^+\pi^-\pi^+\gamma$ will be systematics limited

  → could other hhh systems be more advantageous?

  e.g. $B^+ \to K^+K^-K^+\gamma$ (CF) and KKπγ or $\pi^+\pi^-\pi^+\gamma$ (CS)

  * Exhaustive list of **B → PVγ decays** (*Atwood et al., 2007*)

  → final states with K_S do-able while π^0 nearly impossible

$b \to s\gamma$	$b \to d\gamma$
$B^+ \to \underline{K^+\rho^0\gamma}, K^+\omega\gamma, \underline{K^+\phi\gamma}$	$B^+ \to \underline{\pi^+\rho^0\gamma}, \pi^+\omega\gamma, \underline{\pi^+\phi\gamma}$
$B^+ \to K^0\rho^+\gamma$	$B^+ \to \underline{K^+\bar{K}^{*0}\gamma}$
$B^+ \to \underline{\pi^+K^{*0}\gamma}$	$B^+ \to \underline{\bar{K}^0K^{*+}\gamma}$
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$B^0 \to \underline{K^0\rho^0\gamma}, K^0\omega\gamma, \underline{K^0\phi\gamma}$	$B^0 \to \pi^0\rho^0\gamma, \pi^0\omega\gamma, \pi^0\phi\gamma$
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	$B^0 \to \eta'\rho^0\gamma, \eta'\omega\gamma, \eta'\phi\gamma$
$B_s \to \underline{K^+K^{*-}\gamma}$	$B_s \to \underline{\pi^+K^{*-}\gamma}$
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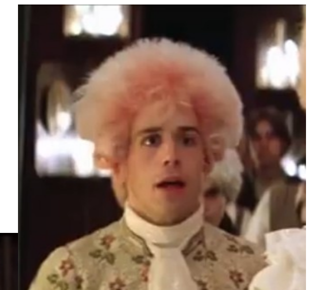
  With connections with anomalies in b2sll: fix C_7(‘) in global fits of $C_{9,10}$, charm-loops contribute to radiative observables, converted photons can be used as cross-checks of RX-electrons etc...

And there are simply too many “modes”, that's all. Cut a few and it will be perfect.



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  $\to$ could other hhh systems be more advantageous?

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$B_s \to \eta\rho^0\gamma, \eta\omega\gamma, \eta\phi\gamma$	$B_s \to \underline{\bar{K}^0\rho^0\gamma}, \bar{K}^0\omega\gamma, \underline{\bar{K}^0\phi\gamma}$
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- **Run3** statistics will boost all statistically limited analysis (baryons, TD-CPV, b2cγ, non-hadronics)

  New data-taking paradigm → signal selections in trigger (watch out for exotic signatures)

- New decay modes or analysis tools? Speak up!

  * Mesons made of two heavy quarks ($B_c^+ \to D_{(s)}^{*+}\gamma$), more EWP @ low-$q^2$ (φe^+e^-, $K\pi\pi e^+e^-$)

  * Partial reconstruction ($B \to \mu\mu(\gamma)$, $K\pi(\pi^0)\gamma$), improved converted photon reconstruction

Backups

$B^0 \to K^* e^+ e^-$ at very low q^2 [JHEP 2012 (2020) 081]

Run 1+2 (9fb^{-1}) analysis.

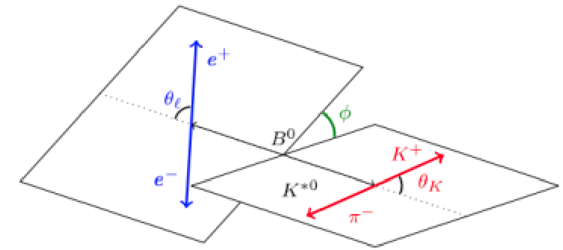
Decay is dominated by $b \to s\gamma$ pole at very low $q^2 \in [0.0008 - 0.257]\ \text{GeV}^2$.

Three relevant angles:

- $\theta_l, \theta_K, \tilde{\phi}$

Four angular observables:

- $F_L, A_T^{Re}, \boldsymbol{A_T^{(2)}}, \boldsymbol{A_T^{Im}}$



$$\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^4(\Gamma+\bar{\Gamma})}{\mathrm{d}q^2\,\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\tilde{\phi}} =$$

$$= \frac{9}{16\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + (1-F_L)A_T^{Re}\sin^2\theta_K\cos\theta_\ell + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\tilde{\phi} + \frac{1}{2}(1-F_L)A_T^{Im}\sin^2\theta_K\sin^2\theta_\ell\sin 2\tilde{\phi}\Big]$$

Sensitive to the polarization of the virtual photon.

$$A_{R(L)} \equiv A_{R(L)}e^{i\phi_{R(L)}},\ \tan\chi \equiv |C_7'/C_7|$$

$$A_T^{(2)} \simeq \sin(2\chi)\cos(\phi_L - \phi_R),$$

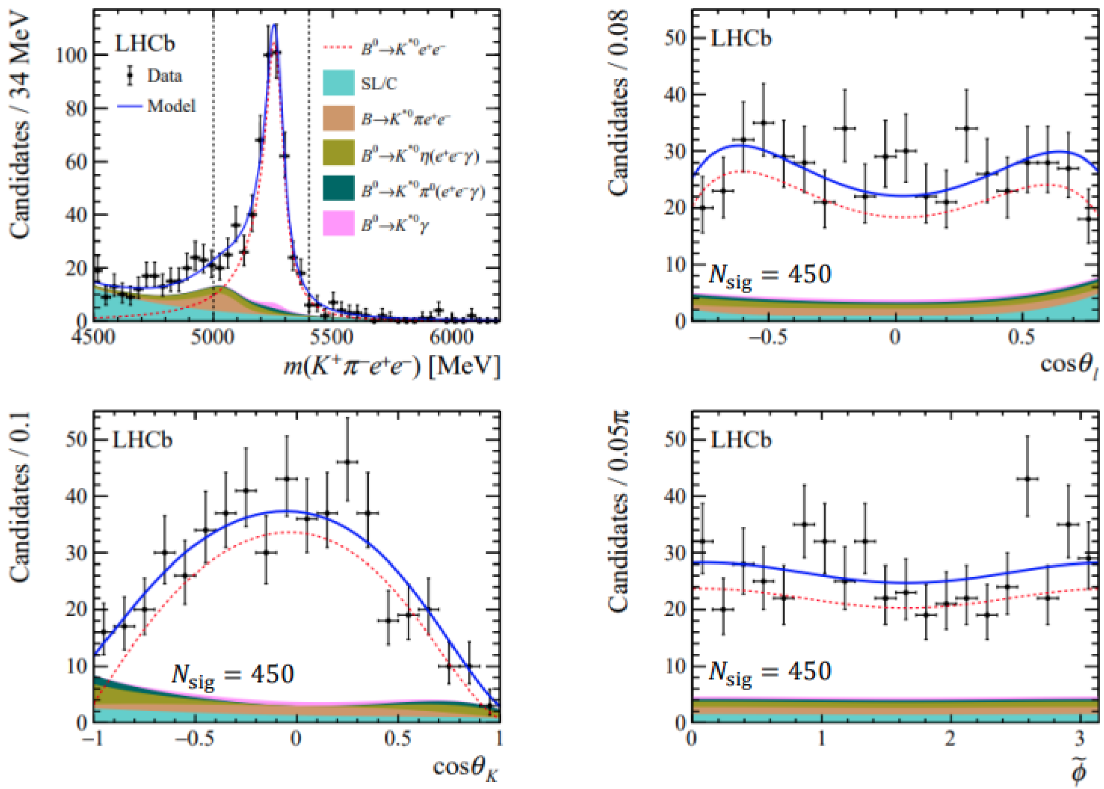
$$A_T^{Im} \simeq \sin(2\chi)\sin(\phi_L - \phi_R),$$

[Nucl. Phys. B854 (2012) 321]

$B^0 \to K^* e^+ e^-$ results

[JHEP 2012 (2020) 081]

Simultaneous fit: $m(K^+\pi^- e^+ e^-)$, $\cos\theta_l$, $\cos\theta_K$, $\tilde{\phi}$

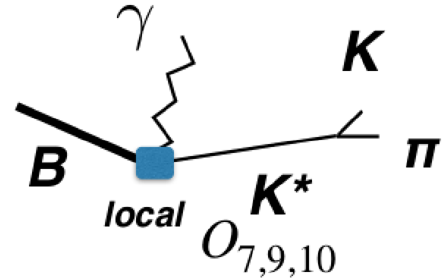


$$F_L = 0.044 \pm 0.026 \pm 0.014,$$
$$A_T^{Re} = -0.06 \pm 0.08 \pm 0.02,$$
$$A_T^{(2)} = +0.11 \pm 0.10 \pm 0.02,$$
$$A_T^{Im} = +0.02 \pm 0.10 \pm 0.01,$$

Uncertainty statistically dominated.

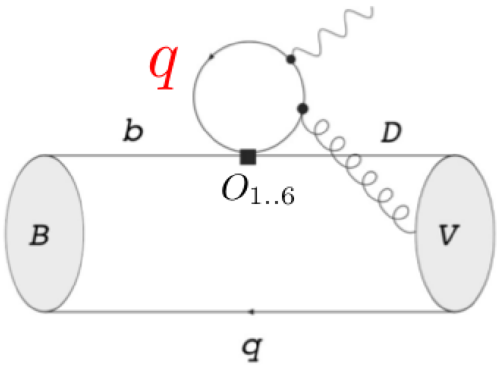
$A_T^{(2)}$ and A_T^{Im} results dominate the senstitivity to Re & Im of $C_7^{(\prime)}$

topologies



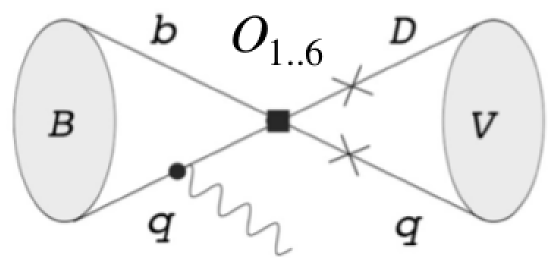
branching fraction

short-dist.



quark-loop

background
right-handed currents

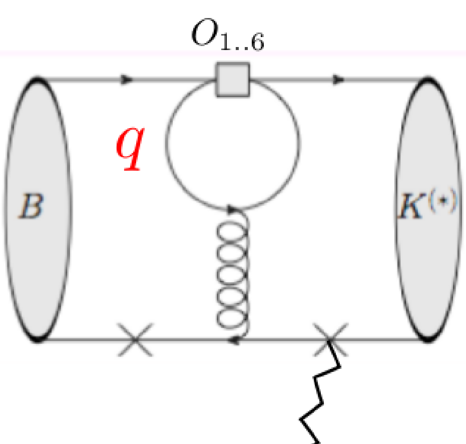


weak annihilation

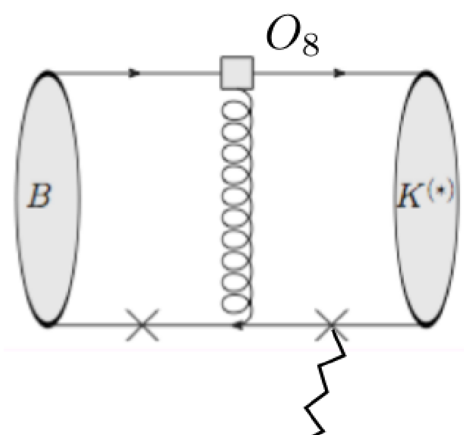
CKM-enhanced b→d

isospin asymmetry

long-distance

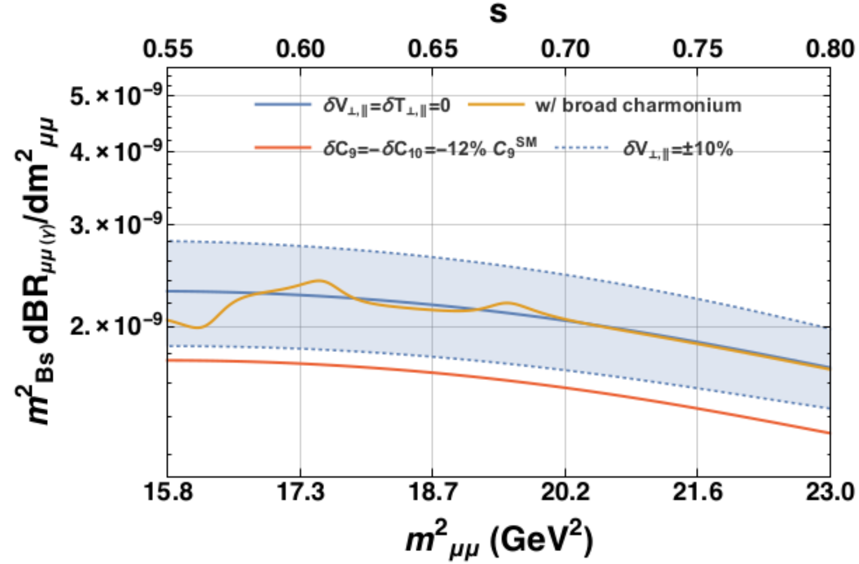


quark-loop scattering



chromo-penguin

[Guadagnoli, Reboud, Zwicky, 2018](#)



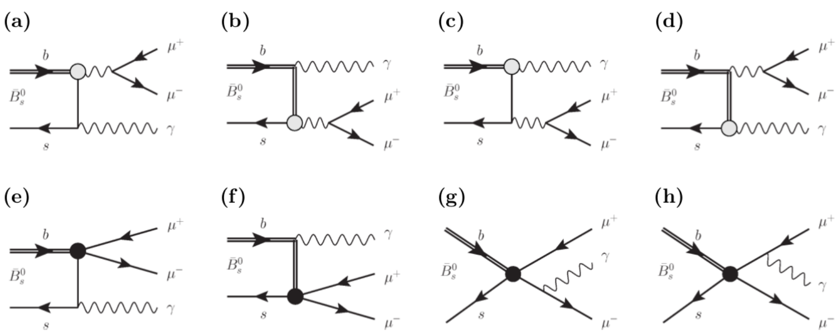


Figure 1: Short-distance diagrams contributing to the $\bar{B}_s^0 \to \mu^+\mu^-\gamma$ process to lowest order. The black and the grey circles denote the insertion of the four-fermion operators $\mathcal{O}_{9,10}^{(\prime)}$ and respectively of $\mathcal{O}_7^{(\prime)}$. The form factors $T_{\perp,\parallel}(q^2,0)$ and $T_{\perp,\parallel}(0,q^2)$ describe the diagrams (a,b) and (c,d) respectively. Diagrams (e) and (f) are described by the $V_{\perp,\parallel}(q^2)$ form factors and diagrams (g) and (h) encode bremsstrahlung contributions, whose hadronic matrix elements are described by the $\bar{B}_s^0$ decay constant.

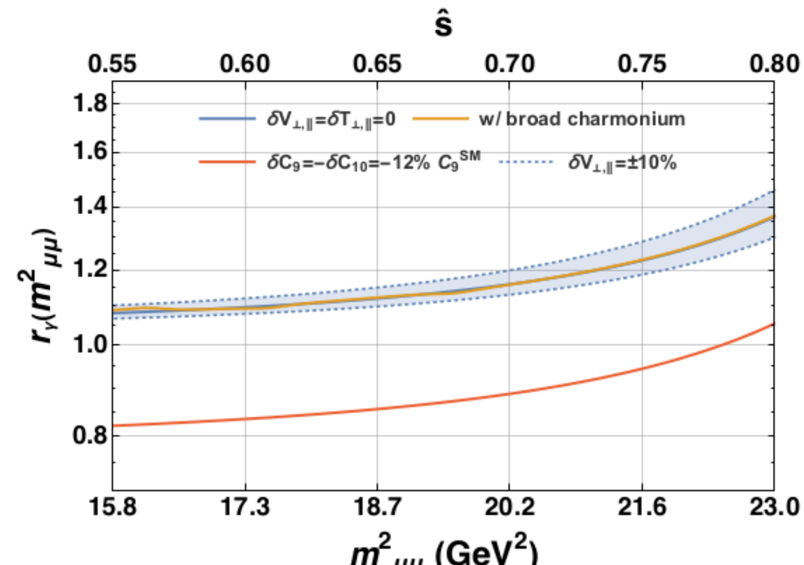


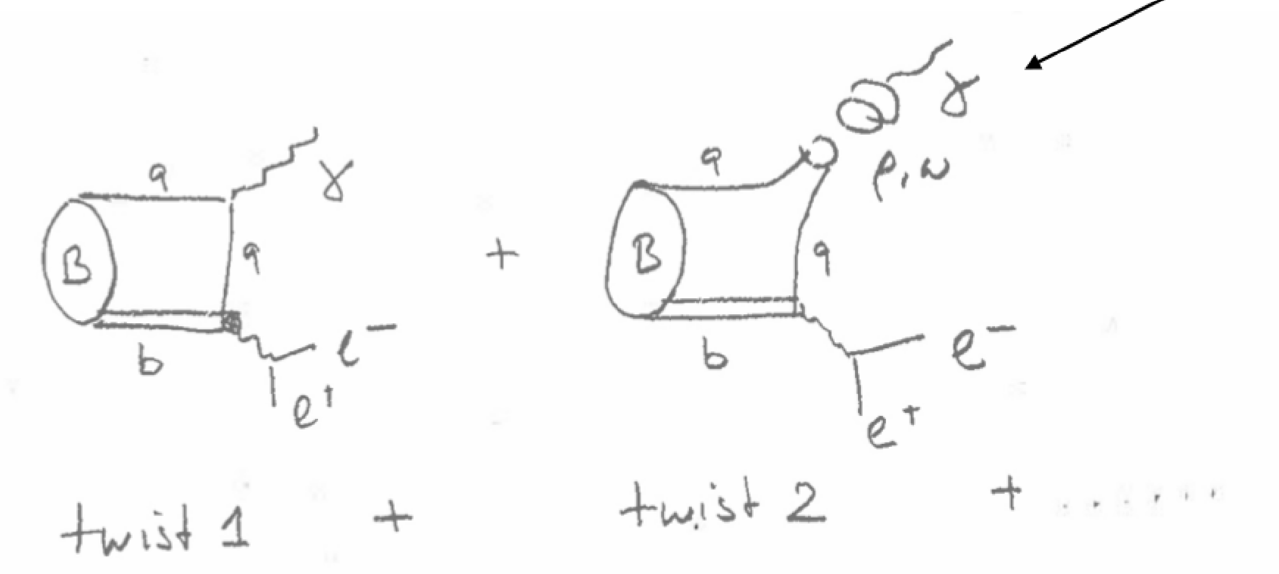
Figure 4: Comparison between (left panel) the theoretical error in the $B_s^0 \to \mu^+\mu^-\gamma$ spectrum and (right panel) the corresponding error on r_γ as defined in eq. (19).

Comment on “non-hadronic” rare decay $B \to \gamma \ell \ell$

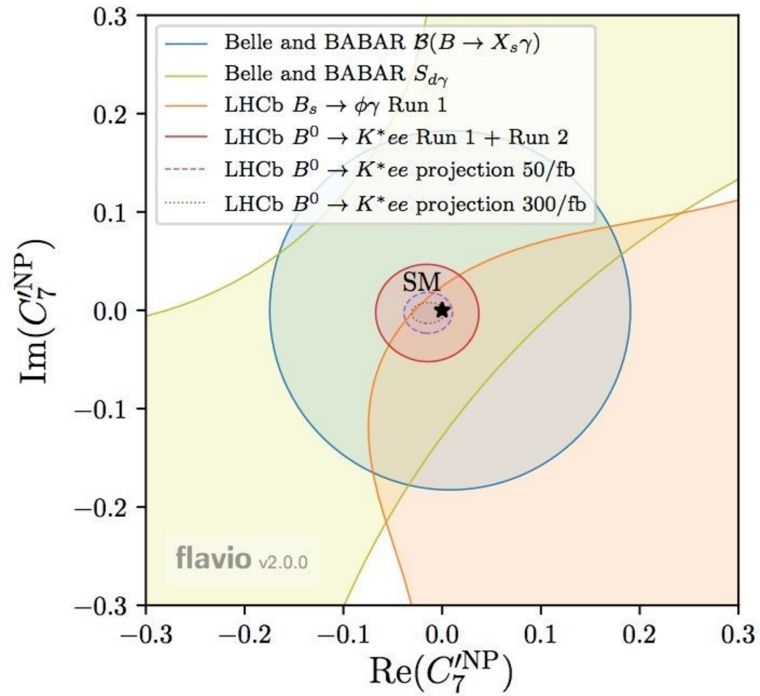
- It’s an **FCNC** there’s a whole zoo of LD-contributions
  no clear advantage over $B \to K^* \ell \ell$

cf. Wang’s talk

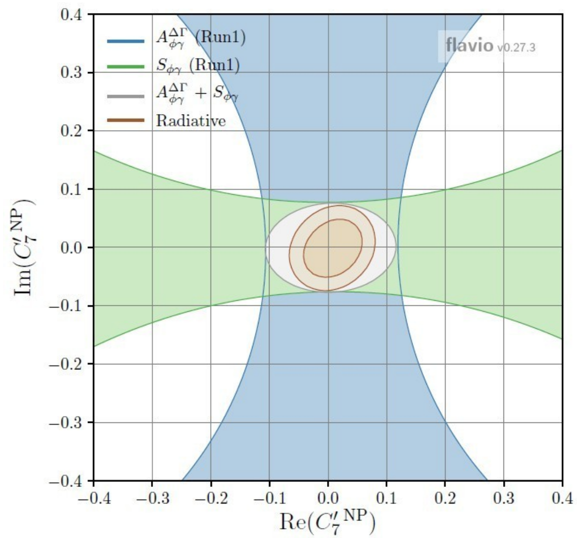
- Even form factor SD contribution has a hadronic component
  (the photon hadronises into $\rho\, \omega' s$ e.g. **photon distribution amplitude**)

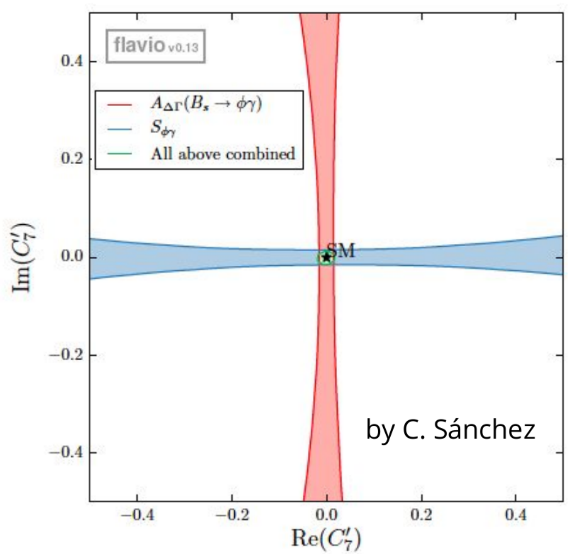


- Photon DA: in large model independent description $\gamma - \rho$ mixing



Belle and BABAR $\mathcal{B}(B \to X_s\gamma)$
Belle and BABAR $S_{d\gamma}$
LHCb $B_s \to \phi\gamma$ Run 1
LHCb $B^0 \to K^*ee$ Run 1 + Run 2
LHCb $B^0 \to K^*ee$ projection 50/fb
LHCb $B^0 \to K^*ee$ projection 300/fb
SM
flavio v2.0.0
$\mathrm{Im}(C_7'^{\mathrm{NP}})$
$\mathrm{Re}(C_7'^{\mathrm{NP}})$





TD-CPV PhiG

CERN-THESIS-2018-429

C. Matordomo

$$\mathcal{A}_{\phi\gamma}^{\Delta} \simeq \frac{2\,\mathrm{Re}\left(e^{-i\phi_s} C_7 C_7'\right)}{|C_7|^2 + |C_7'|^2},$$

$$\mathcal{S}_{\phi\gamma} \simeq \frac{2\,\mathrm{Im}\left(e^{-i\phi_s} C_7 C_7'\right)}{|C_7|^2 + |C_7'|^2},$$

B_d

$$\Gamma(t) \equiv \Gamma(B_q(t) \to M^0\gamma) = e^{-\Gamma t}|A|^2[1 + \xi \sin(2\psi)\sin(\phi_M - \phi_L - \phi_R)\sin(\Delta m t)]$$

B_s

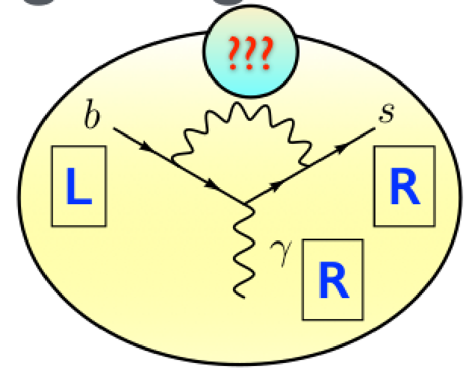
$$e^{-\Gamma_s t}\{\cosh(\Delta\Gamma_s t/2) - \mathcal{A}^{\Delta}\sinh(\Delta\Gamma_s t/2) + \zeta\,\mathcal{C}\cos(\Delta m_s t) - \zeta\,\mathcal{S}\sin(\Delta m_s t)\}$$

$$\mathcal{A}^{\Delta} = \sin(2\psi),\ \text{where}\ \tan\psi \equiv |A(\overline{B}{}_s^0 \to \phi\gamma_{\mathrm{R}})|/|A(\overline{B}{}_s^0 \to \phi\gamma_{\mathrm{L}})|$$

A time-dependent analysis of the $B_s^0 \to \phi\gamma$ decay rate is performed to determine the CP -violating observables $S_{\phi\gamma}$ and $C_{\phi\gamma}$ and the mixing-induced observable $\mathcal{A}_{\phi\gamma}^{\Delta}$. The measurement is based on a sample of pp collision data recorded with the LHCb detector, corresponding to an integrated luminosity of 3 fb^{-1} at center-of-mass energies of 7 and 8 TeV. The measured values are $S_{\phi\gamma} = 0.43 \pm 0.30 \pm 0.11$, $C_{\phi\gamma} = 0.11 \pm 0.29 \pm 0.11$, and $\mathcal{A}_{\phi\gamma}^{\Delta} = -0.67^{+0.37}_{-0.41} \pm 0.17$, where the first uncertainty is statistical and the second systematic. This is the first measurement of the observables S and C in radiative B_s^0 decays. The results are consistent with the standard model predictions.

DOI: 10.1103/PhysRevLett.123.081802

Which NP models we are targeting?



- What types of new physics models?
  For example, models with right-handed neutrino, or custodial symmetry in general induces the right handed current.

Left-Right symmetric model (W_R)	SUSY GUT model δ_{RR} mass insertion
Blanke et al. JHEP1203	*Girrbach et al. JHEP1106*

- Which flavour/Dirac structure?
  The models that contain new particles which change the chirality inside of the b➔sγ loop can induce a large chiral enhancement!

Left-Right symmetric model: mt/mb	SUSY with δ_{RL} mass insertions: m_{SUSY}/m_b
Cho, Misiak, PRD49, '94 *Babu et al PLB333 '94*	*Gabbiani, et al. NPB477 '96* *Ball, EK, Khalil, PRD69 '04*

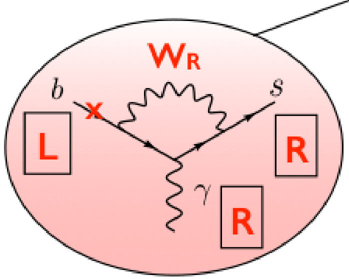
NP signal beyond the constraints from Bs oscillation parameters possible.

Chiral enhancement in LRSM

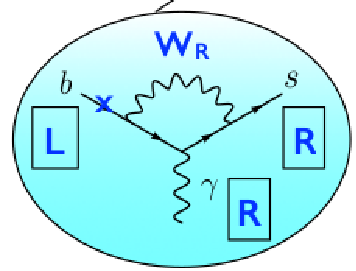
Right handed-photon contribution

$$C'_{7\gamma}(\mu_R) = \frac{1}{2}\Bigg[\frac{g_R^2}{g_L^2}\frac{V_{ts}^{R*}V_{tb}^{R}}{V_{ts}^{L*}V_{tb}^{L}}\left(\sin^2\zeta\, A_{\rm SM}(x_t) + \cos^2\zeta\,\frac{M_1^2}{M_2^2}A_{\rm SM}(\tilde{x}_t)\right)$$

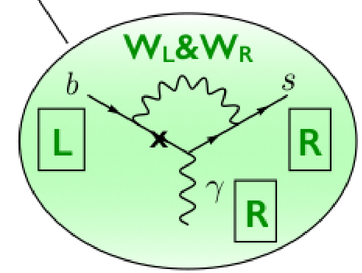
$$+\frac{m_t}{m_b}\frac{g_R}{g_L}\frac{V_{ts}^{R*}}{V_{ts}^{L*}}\sin\zeta\cos\zeta\, e^{-iw}\left(A_{\rm LR}(x_t) - \frac{M_1^2}{M_2^2}A_{\rm LR}(\tilde{x}_t)\right) + \ldots$$



W_R contribution from W_1; Proportional to mb but suppressed by $1/M_2^2$



W_R contribution from W_2; Proportional to mb



W_L & W_R mixing contribution; proportional to mt !

Chiral enhancement term