# Radiative decays at LHCb


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- Motivation
- LHCb detector and data taking
- First observation of $\Lambda_b^0 \rightarrow \Lambda\gamma$
- Time-dependent analysis of $B_s^0 \rightarrow \phi\gamma$
- Summary

Beauty 2019

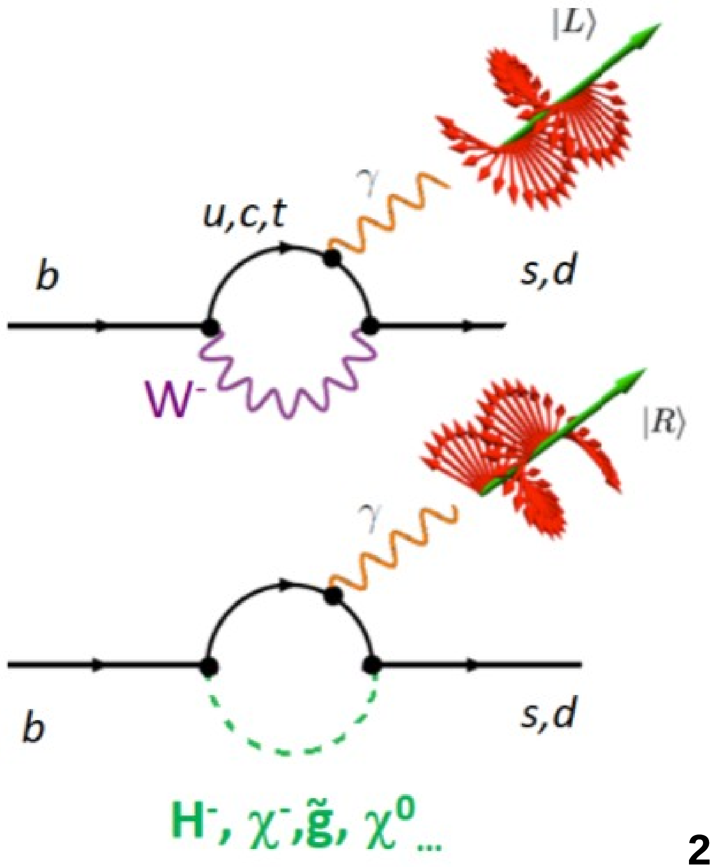
# Radiative b decays

b→ s(d)γ are Flavour-Changing-Neutral-Currents →

- forbidden at tree level in Standard Model (SM), only occurs via loop diagrams in SM,
- indirect search can probe New Physics at much larger scales

SM: left-handed W induces purely left-handed photon

- Probing for New Physics by measurement of:
  - photon polarization
  - Branching fractions and direct CP violation parameters

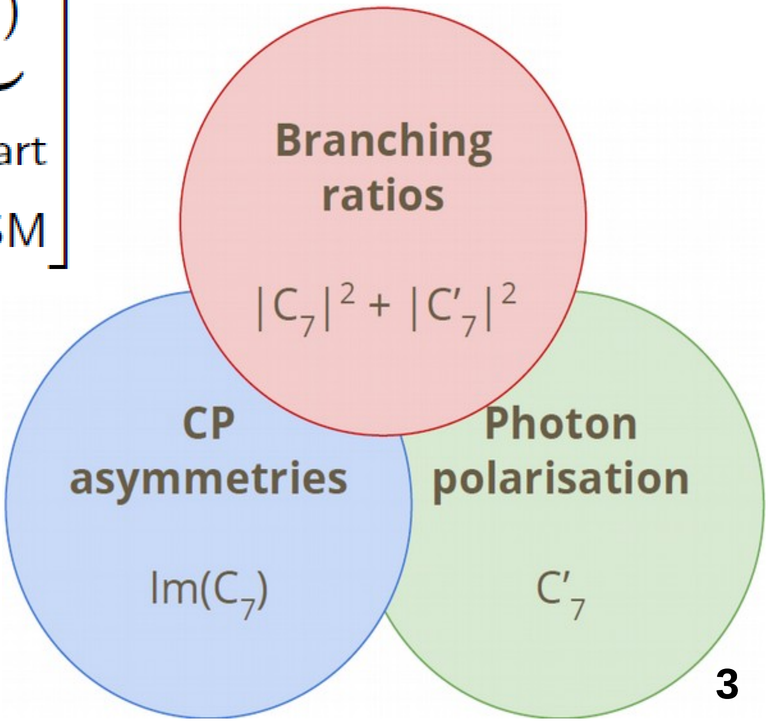


# Radiative b decays observables

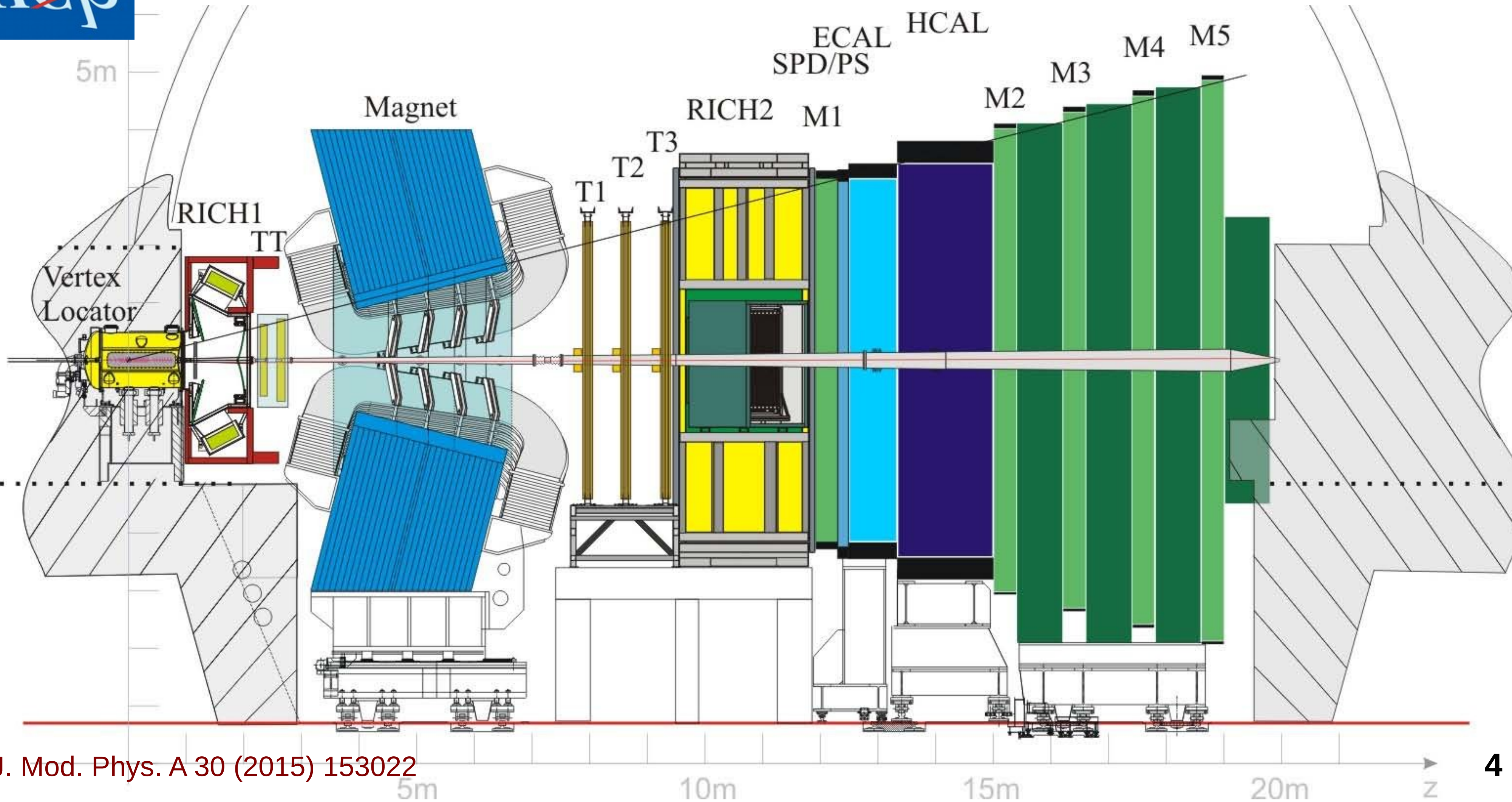
Wilson Coefficient

$$H_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^{*} \sum_i \left[ \underbrace{\mathcal{C}_i(\mu)\, \mathcal{O}_i(\mu)}_{\text{left-handed part}} + \underbrace{\mathcal{C}'_i(\mu)\, \mathcal{O}'_i(\mu)}_{\substack{\text{right-handed part} \\ \text{suppressed in SM}}} \right]$$

- Due to the chiral structure of W bosons, in the SM the photon polarization is predominantly left-handed: $C`_7$ / $C_7$ ~ O ($m_s$/$m_b$) ~ 0.02
- In some models (like LRSM),|$A_R$ / $A_L$| up to 0.5 [JHEP 12 (2013) 102]



# LHCb experiment

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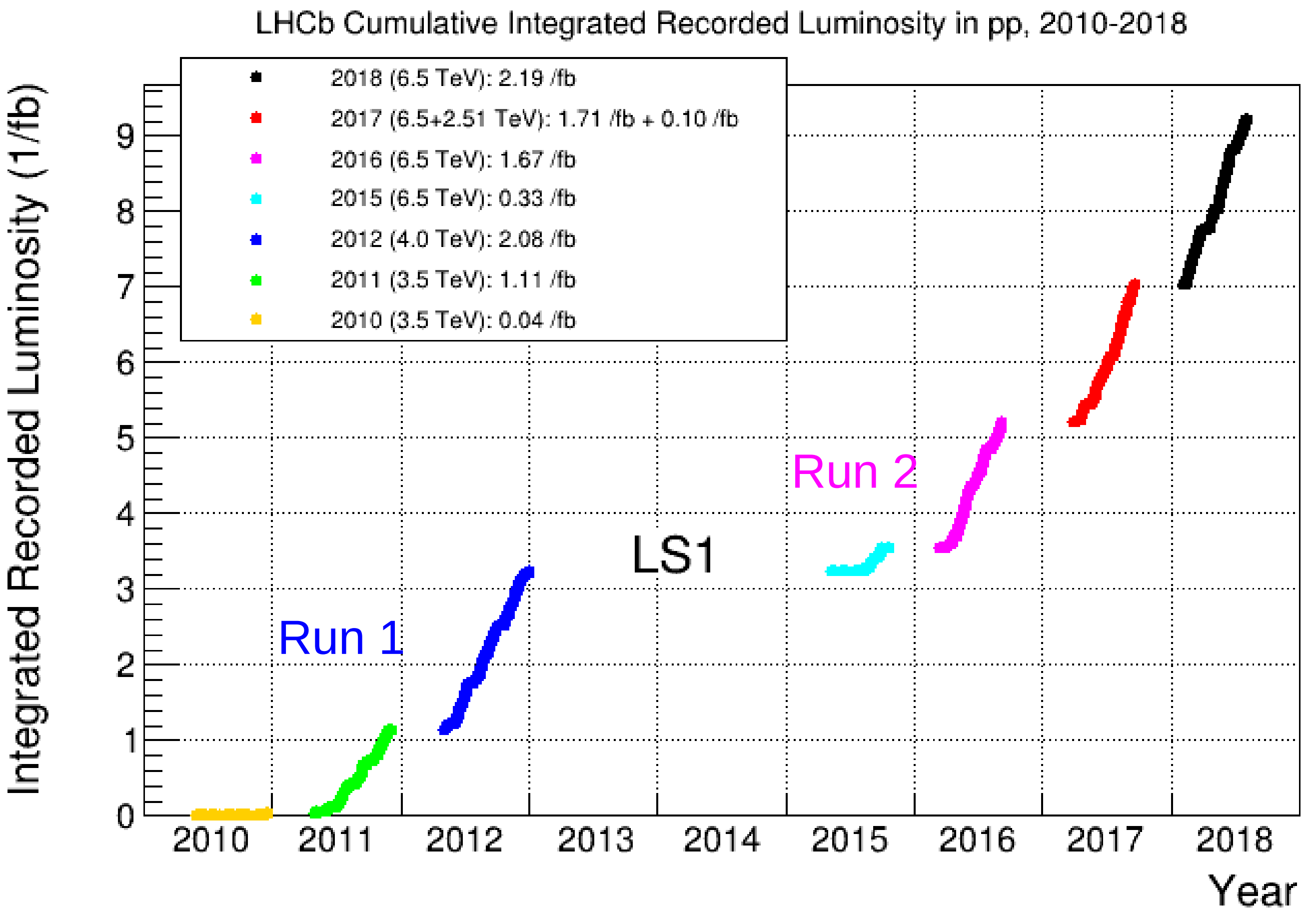
# LHCb performance

Acceptance: $2 < \eta < 5$




- Trigger efficiency: ~ 40% for hadronic channels
- Momentum resolution: 0.4-0.6% at 5 – 100 GeV
- Kaon ID efficiency: 95% with 5 % $\pi \rightarrow K$ mis-ID probability
- Energy resolution for photons: $1\% + 10\% / \sqrt{E(\text{GeV})}$

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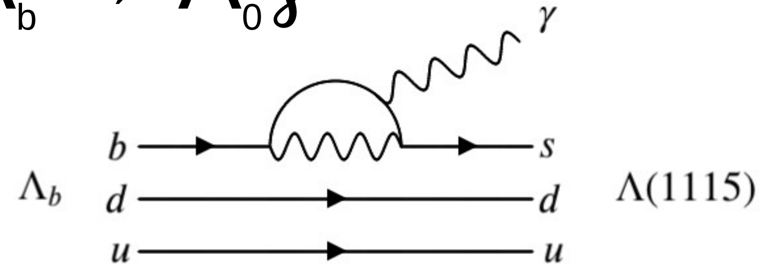
# Beauty baryonic radiative decays

- LHCb has unique dataset of beauty baryons:
  - $\Lambda_b^0 \to \Lambda\mu^+\mu^-$ BF JHEP09(2018)145, moments JHEP09(2018)146;
  - $\Lambda_b^0 \to \Lambda^*\mu^+\mu^-$ JHEP06(2017)108, $\Lambda_b^0 \to N^*\mu^+\mu^-$ JHEP04(2017)029.

- Baryonic $b \to s\gamma$ has not observed.
- Gives access to photon polarisation: ground state $\Lambda_b^0(\uparrow)$  $|b(\uparrow)[ud]>$, the [ud] system acts as spectator diquark. The $\Lambda_b^0$ respects properties of the underlying b-quark.
- For $\Lambda_b^0$ decays, normal to the plane formed by the pp-collision and $\Lambda_b^0$ spin directions provide a preferred plane (even for unpolarized $\Lambda_b^0$, as in LHCb).

# Search for $\Lambda_b \to \Lambda_0\gamma$

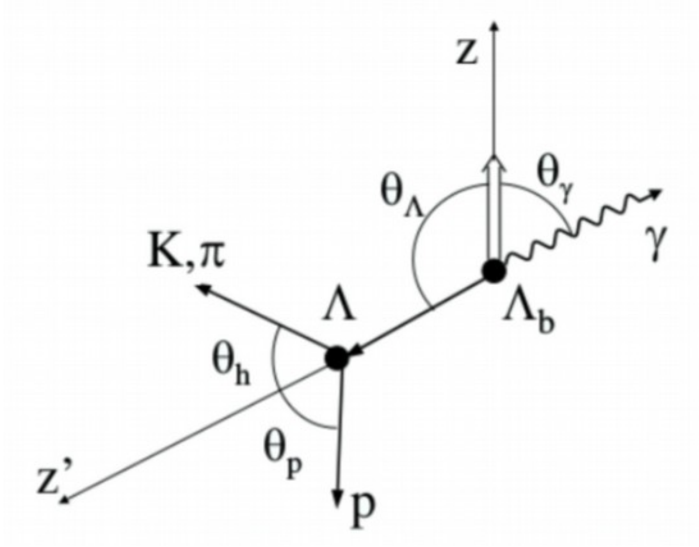



- SM prediction for B from $10^{-7}$ to $10^{-5}$
- CDF: B < $1.9 \cdot 10^{-3}$ [Phys.Rev.D66 112002]

- Using LHCb Run2 2016 data (1.7 $fb^{-1}$)

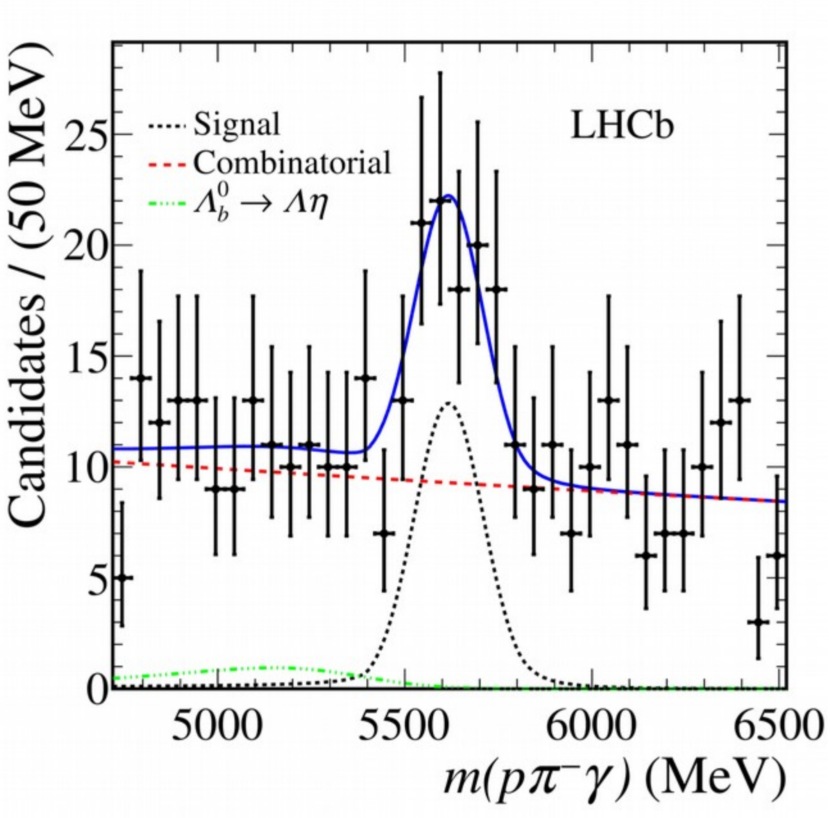
- Very challenging mode: no secondary vertex, long lifetime ($c\tau$ = 8cm), no direction from cluster

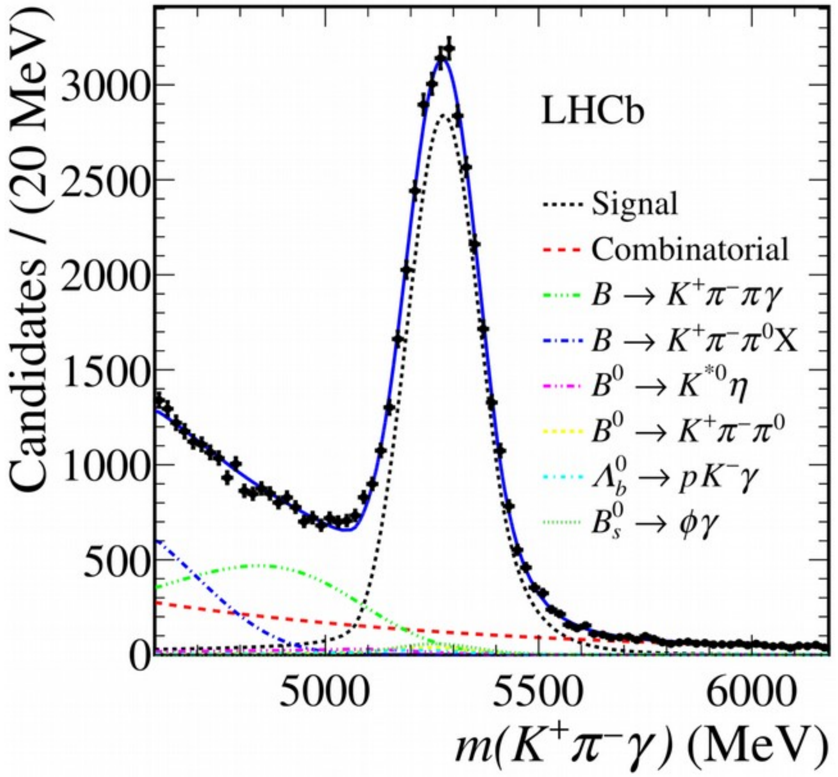
- Using $B^0 \to K^{*0}\gamma$ as a normalization channel




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

# First observation of $\Lambda_b^0 \to \Lambda\gamma$




5.6σ signicance

$B(\Lambda_b^0 \to \Lambda\gamma) = (7.1 \pm 1.5_{stat} \pm 0.6_{syst} \pm 0.7_{ext})\ 10^{-6}$

Run2: 1.7 fb$^{-1}$

Phys. Rev. Lett. 123 (2019) 031801

# More about $\Lambda_b^0 \to \Lambda\gamma$

Analysis statistically limited. Main systematics:

| Source | Uncertainty (%) |
|---|---|
| Data/simulation agreement | 7.7 |
| $\Lambda_b^0$ fit model | 3.0 |
| $B^0 \to K^{*0}\gamma$ backgrounds | 2.7 |
| Size of simulated samples | 1.7 |
| Efficiency ratio | 0.7 |
| Sum in quadrature | 8.9 |
| $f_{\Lambda_b^0}/f_{B^0}$ | 8.7 |
| Input branching fractions | 3.0 |
| Sum in quadrature | 9.2 |

Run2: 1.7 $fb^{-1}$

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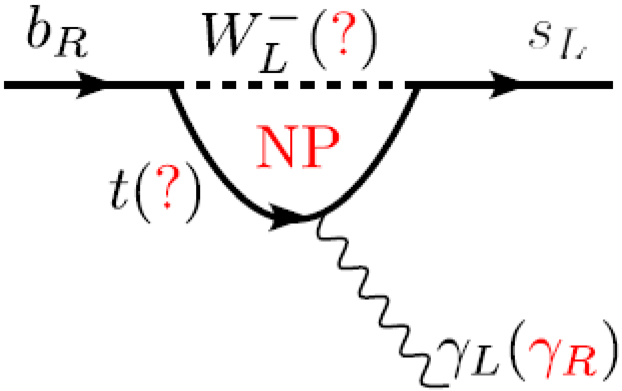
# Photon polarization in b→sγ



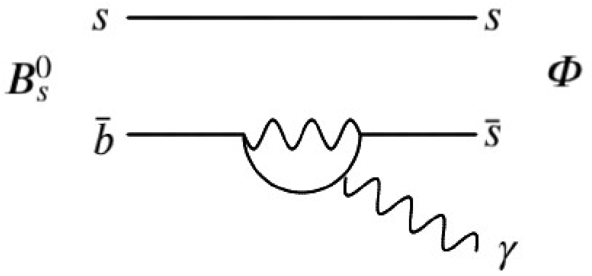

- In SM γ is purely left-handed due to angular momentum conservation

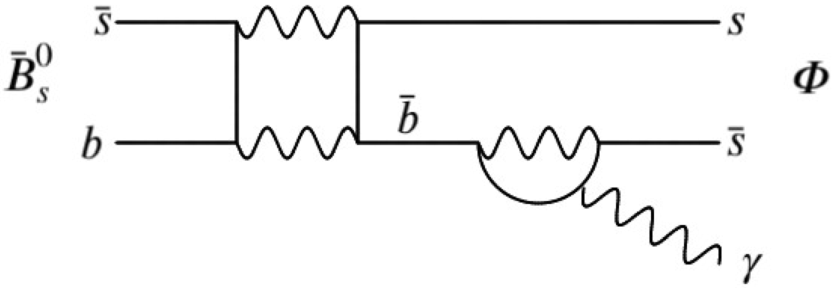
$$\mathcal{M} \propto \underbrace{\left(C_{7\gamma}^{\rm SM} + C_{7\gamma}^{\rm NP}\right) \mathcal{O}_{7\gamma}}_{\mathcal{M}_L} + \underbrace{\left(C_{7\gamma}^{\prime\rm SM} + C_{7\gamma}^{\prime\rm NP}\right) \mathcal{O}_{7\gamma}^{\prime}}_{\mathcal{M}_R}$$

- Leading operator in SM: $\mathcal{O}_{7\gamma} = [\bar{s}\sigma_{\mu\nu}(1+\gamma_5)bF^{\mu\nu}]$
- Chirally-flipped term is suppressed: $\mathcal{O}_{7\gamma}^{\prime} = [\bar{s}\sigma_{\mu\nu}(1-\gamma_5)bF^{\mu\nu}],\ C_{7\gamma}^{\prime\rm SM} \sim \frac{m_s}{m_b} C_{7\gamma}^{\rm SM}$

- But it enhanced in many NP scenarios (RH $W_R^-$ , SUSY)
- RH photon: excellent null test for SM

# Photon polarization in $B_s^0 \rightarrow \varphi\gamma$




Time-dependent decay rates for $B_s^0 \rightarrow \phi\gamma$ and $\bar{B}_s^0 \rightarrow \phi\gamma$ gives access to the photon polarization :

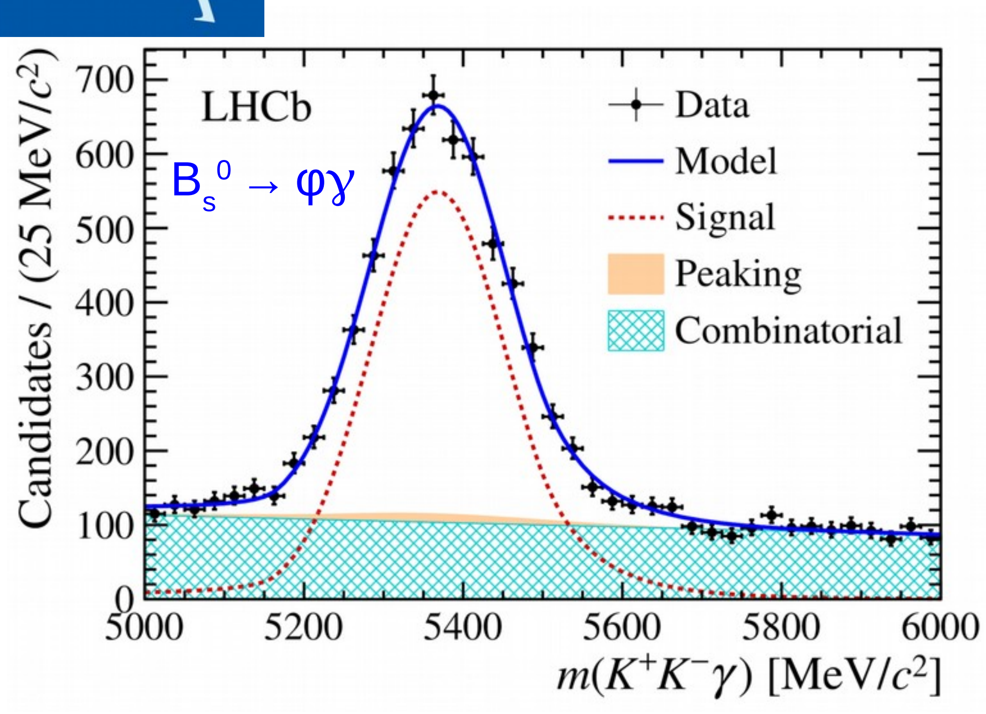
$$\Gamma_{B_S^0\to\Phi\gamma}(t) \propto \left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) - \mathcal{A}\sinh\left(\frac{\Delta\Gamma_s t}{2}\right) + C\cos(\Delta m_s t) - S\sin(\Delta m_s t)\right]$$

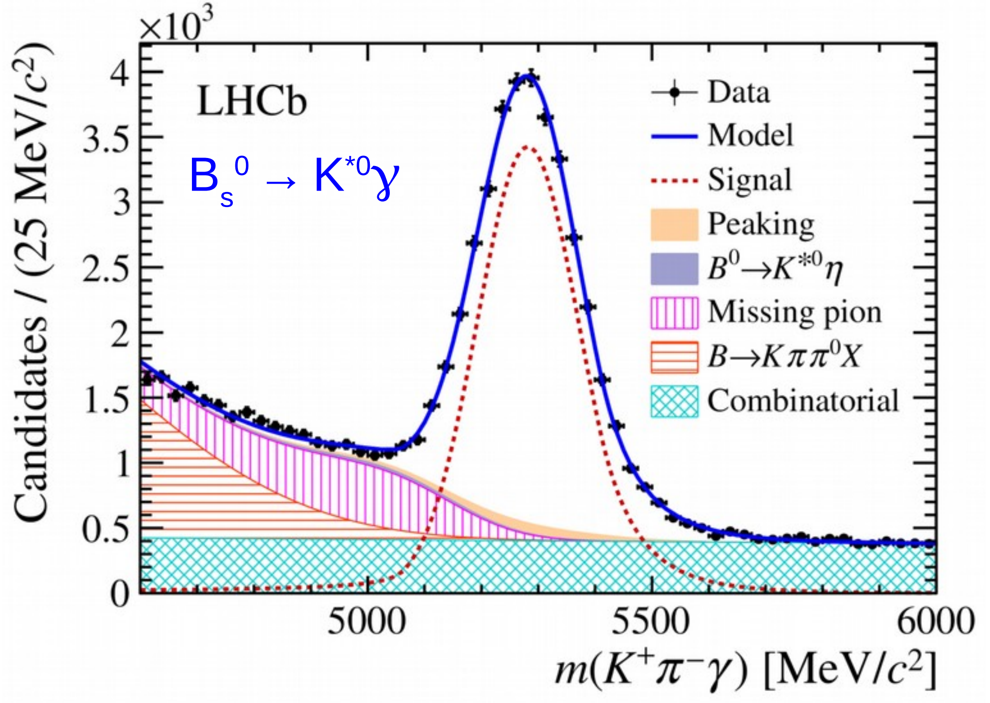
$$\Gamma_{\bar{B}_S^0\to\Phi\gamma}(t) \propto \left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) - \mathcal{A}\sinh\left(\frac{\Delta\Gamma_s t}{2}\right) - C\cos(\Delta m_s t) + S\sin(\Delta m_s t)\right]$$

Depend on $C_7$ and $C_7'$

- $\Delta\Gamma_s$ & $\Delta m_s$ : decay width and mass differences between the $B_s^0$ mass eigenstates
- C: measure of the direct CP violation, S: measure of the $B_s^0$ - $\bar{B}_s^0$mixing

# Photon polarization in $B_s^0 \to \phi\gamma$



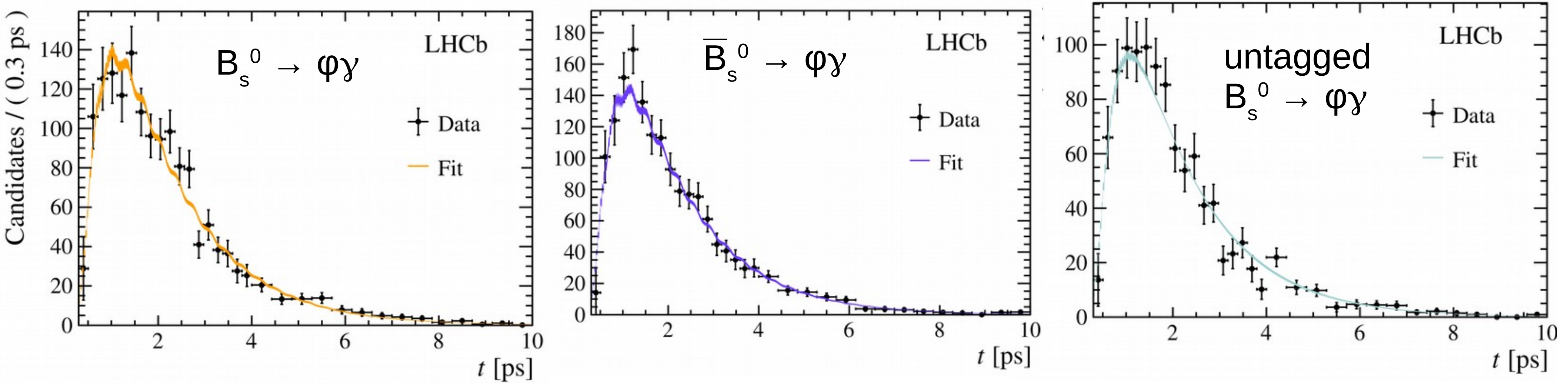

- Selection: $E_T(\gamma)$> 3 GeV, $p_T(B)$> 3 GeV, PID cuts, $\gamma$-$\pi^0$ separation.
- Using $B_s^0 \to K^{*0}\gamma$ as a high statistics control mode for decay-time acceptance.

Run1: 3.0 $fb^{-1}$

arXiv: 1905.06284

# Photon polarization in $B_s^0 \rightarrow \varphi\gamma$

- $B^0 \rightarrow K^{*0}\gamma$ is used as control channel for decay time efficiency.
- Fit of $B_s^0$ mass to obtain a background subtracted time-dependent decay rate taking into account event mis-tag probability and decay time uncertainty.




$S = 0.43 \pm 0.30 \pm 0.11$ 1.3 σ from SM

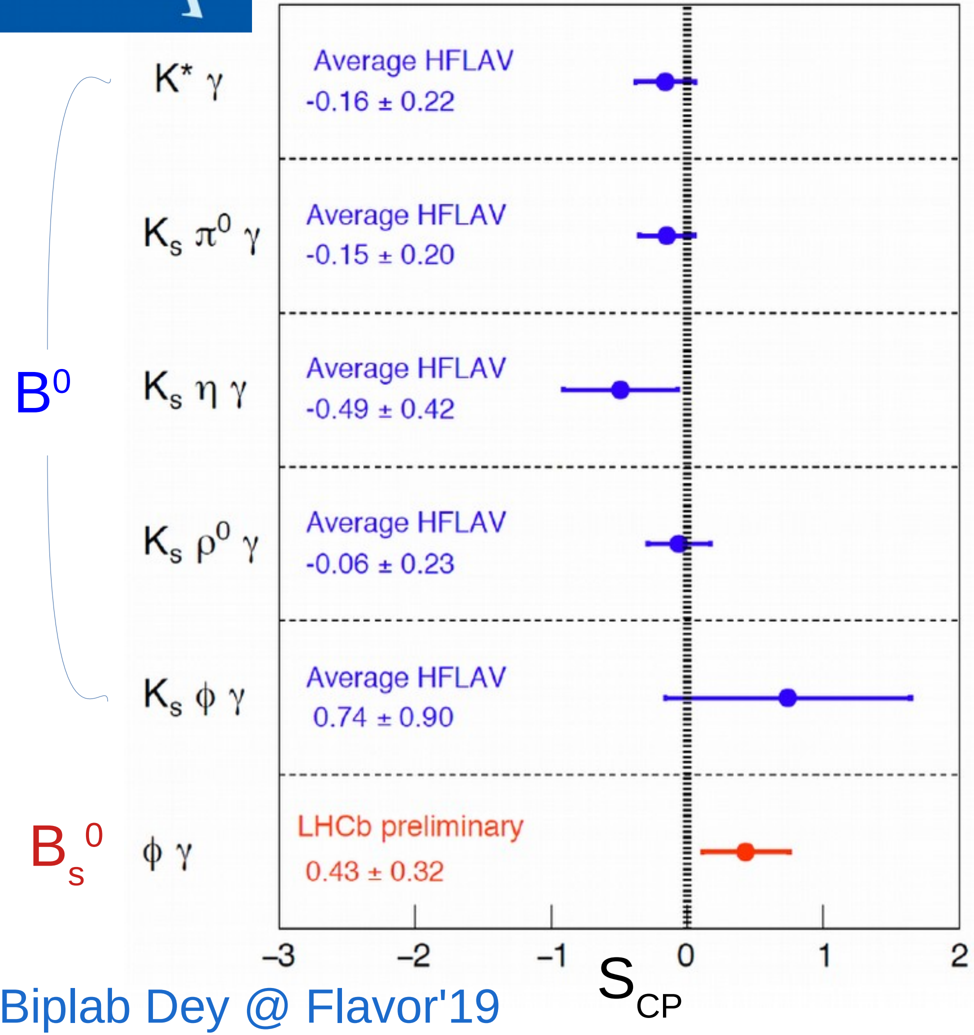
$C = 0.11 \pm 0.29 \pm 0.11$ 0.3 σ from SM

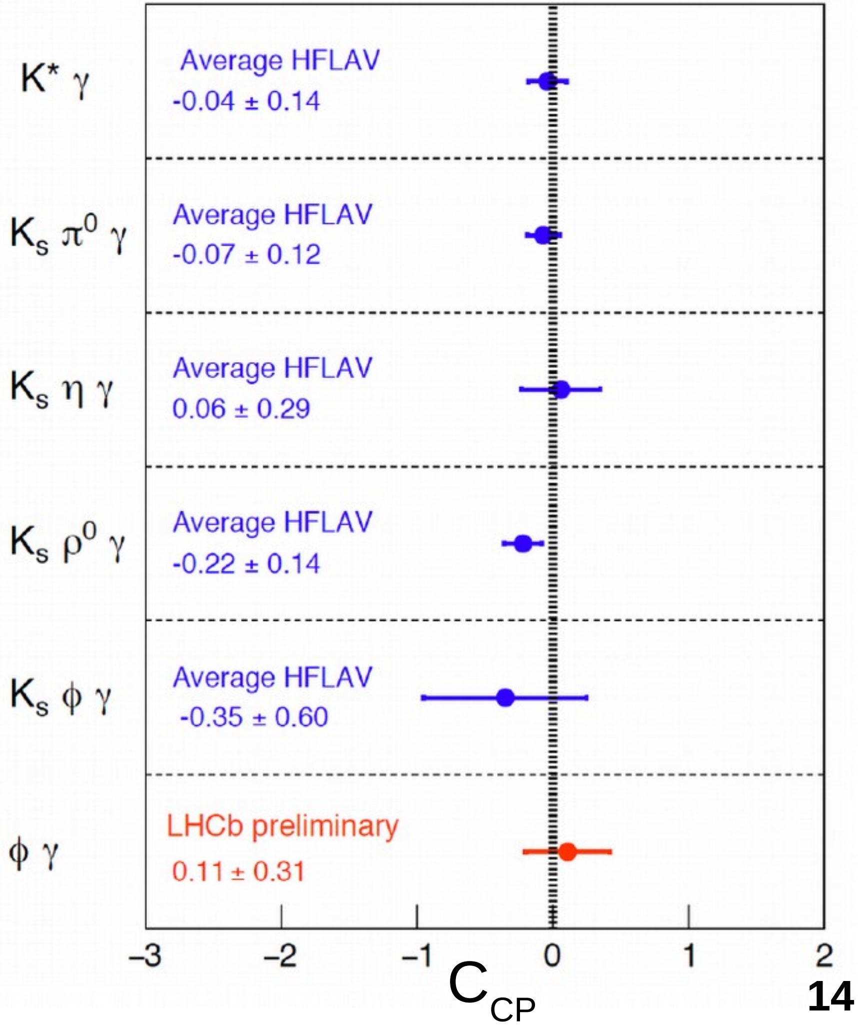
$A = -0.67^{+0.37}_{-0.41} \pm 0.17$ 1.7 σ from SM

Run1: 3.0 $fb^{-1}$

arXiv: 1905.06284

# Global radiative TD CPV



# Summary

- The photon polarization in $b \to s\gamma$ is highly sensitive to NP.
- Complementary approaches by measurements of branching-fractions, angular analyses and CP asymmetries.
- New LHCb results:
  - first radiative b-baryon decay observed,
  - new measurement of photon polarization.
- More to come soon from LHCb full Run 2 analyses

  … and Belle II, LHCb phase 2 ...

# LHCb upgrade schedule