Radiative decays at LHCb

Carlos Sánchez Mayordomo,
on behalf of the LHCb Collaboration

10th CKM workshop
Heidelberg, Germany

20th September 2018

EXCELENCIA
SEVERO
OCHOA

VNIVERSITAT
DE VALÈNCIA

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

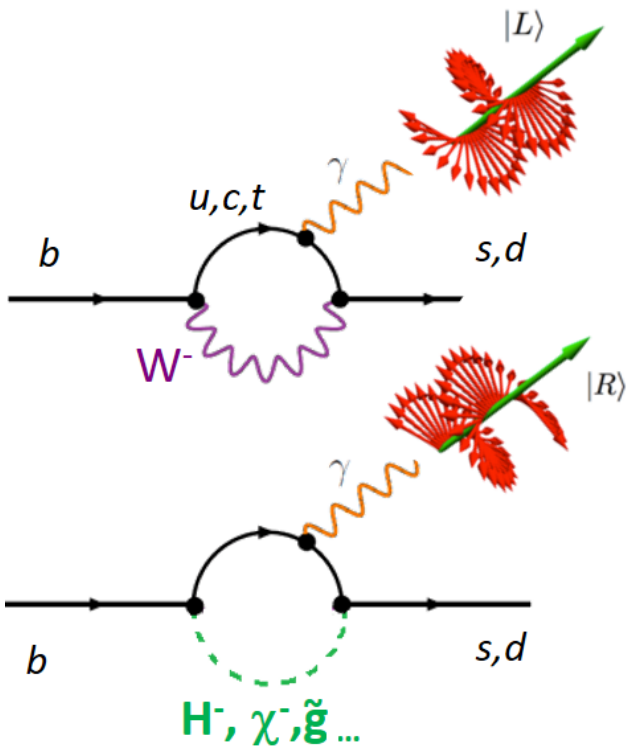
Outline

- Photon polarization

- Angular $B^+ \to K^+\pi^-\pi^+\gamma$ *LHCb: PRL 112 161801 (2014)*
- Angular $B^0 \to K^{*0}e^+e^-$ *LHCb: JHEP 04 064 (2015)*
- Time-dependent $B_s^0 \to \phi\gamma$
  - A^Δ measurement *LHCb: PRL 118 021801 (2017)*
  - S_{CP} and C_{CP} measurement *Ongoing...*
- b-baryon decays ($\Lambda_b^0 \to \Lambda^0\gamma$, $\Xi_b^- \to \Xi^-\gamma$) *Ongoing...*

Photon polarization

- New physics could modify the photon polarization in $b \to s\gamma$



- Photons are predominantly left-handed in the SM
- In some models (like LRSM), $|A_R/A_L|$ up to 1/2

F.Yu et al.: JHEP 12 102 (2013)

- Photon polarization is complementary to BR measurements

Effective weak theory

Effective Hamiltonian of the $b \to s$ transition:

$$\langle f | H_{\text{eff}} | i \rangle = -\frac{4G_F}{\sqrt{2}} V_{\text{tb}} V_{\text{ts}}^* \sum_k C_k(\mu) \langle f | \mathcal{O}_k(\mu) | i \rangle$$

Radiative decays are sensitive to the electromagnetic operators:

$$\mathcal{O}_7 = \frac{e}{16\pi^2} m_b (\bar{s} \sigma_{\mu\nu} P_R b) F^{\mu\nu} \qquad (b_R \to s_L \gamma_L \text{ with strength } m_b)$$

$$\mathcal{O}_7' = \frac{e}{16\pi^2} m_b (\bar{s} \sigma_{\mu\nu} P_L b) F^{\mu\nu} \qquad (b_L \to s_R \gamma_R \text{ with strength } m_s)$$

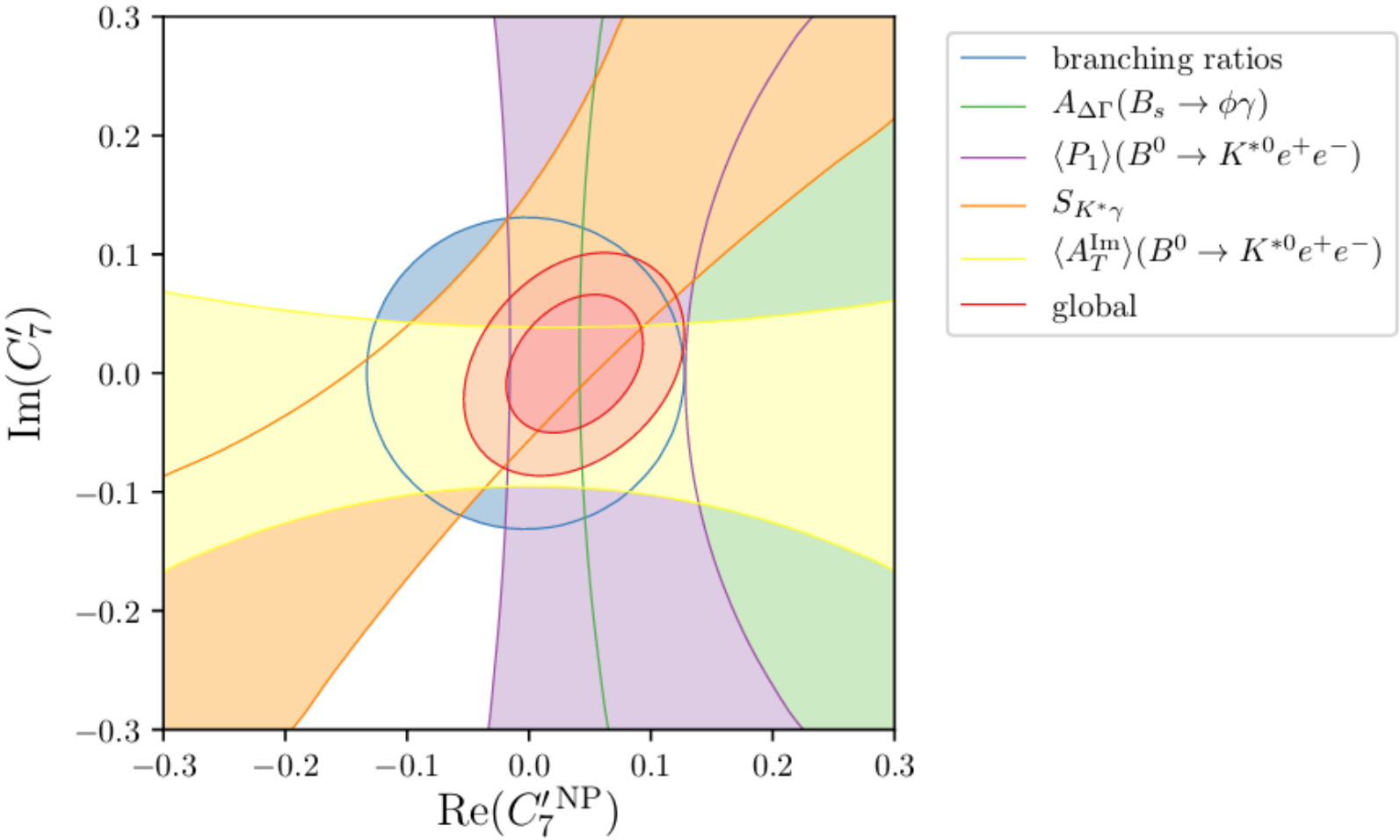
Ratio of right-left helicities (in SM):

$$\frac{A_R}{A_L} = \frac{C_7'}{C_7} = \frac{m_s}{m_b} = 0.02$$

S. Descotes-Genon et al.: JHEP 06 099 (2011)

Current C_7' constraints

From radiative decays



→ *See David Straub talk!* *A.Paul and D.Straub: JHEP 1704 027 (2017)*

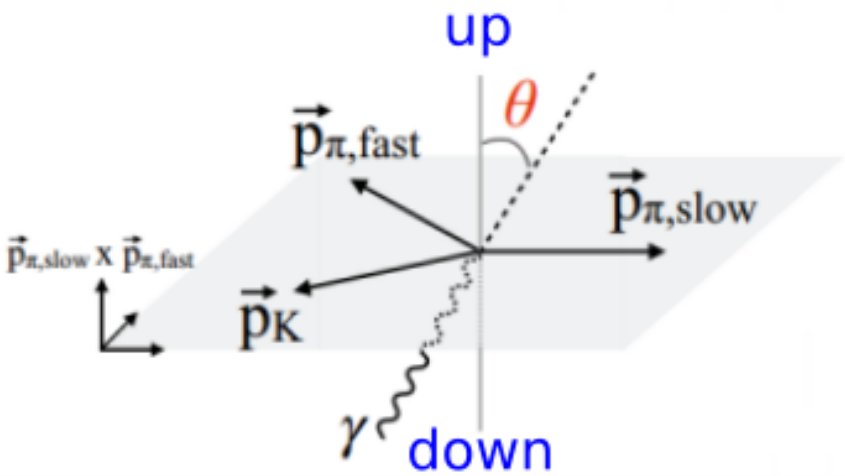
Photon polarization in $B^+ \to K^+\pi^-\pi^+\gamma$

First observation of photon polarization in $b \to s\gamma$

LHCb: PRL 112 161801 (2014)

- Three-body decays in $B \to K_{\text{res}}(\to K\pi\pi)\gamma$
- The direction of the photon is defined by the $K\pi\pi$ plane
- Photon polarization:

$$\lambda_\gamma = \frac{|C_7'|^2 - |C_7|^2}{|C_7'|^2 + |C_7|^2}$$



- Up-down asymmetry A_{ud}:

$$A_{\text{ud}} \equiv \frac{N_{\text{up}}(\cos\theta > 0) - N_{\text{down}}(\cos\theta < 0)}{N_{\text{total}}} \propto \lambda_\gamma$$

→ *See E.Kou talk!*

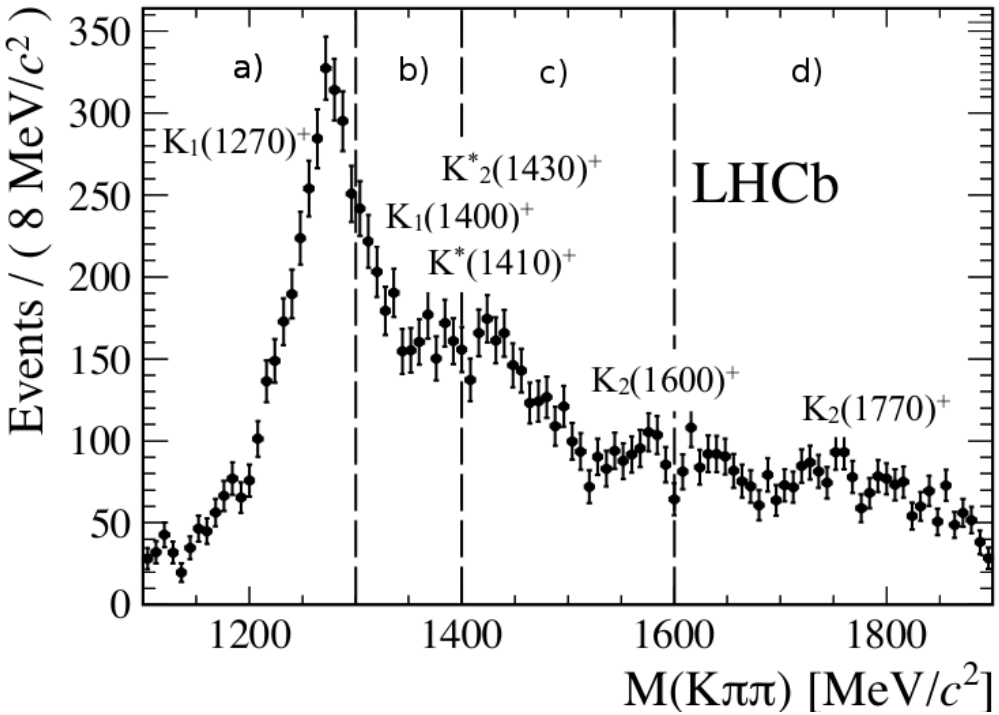
M.Gronau and D.Pirjol: PRD 96 013002 (2017)

S.Akar et al.: arXiv:1802.09433 (2018)

Photon polarization in $B^+ \to K^+\pi^-\pi^+\gamma$

LHCb: PRL 112 161801 (2014)

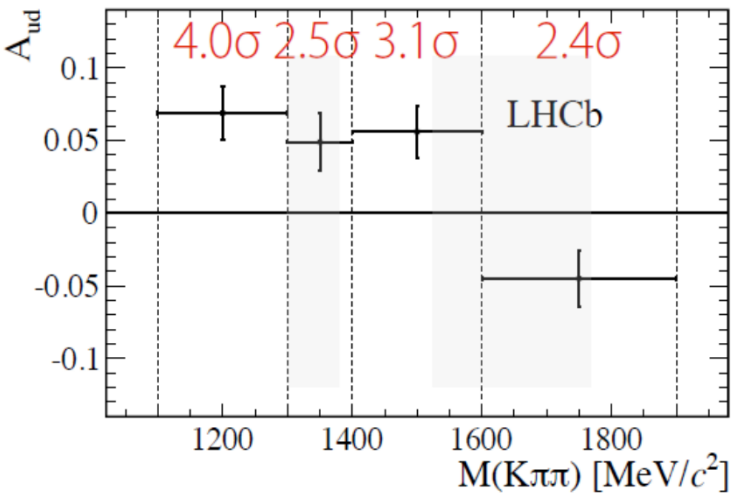
- Several resonances contribute
- Analysis in four regions of the K_{res} mass $14\,000$ signal events



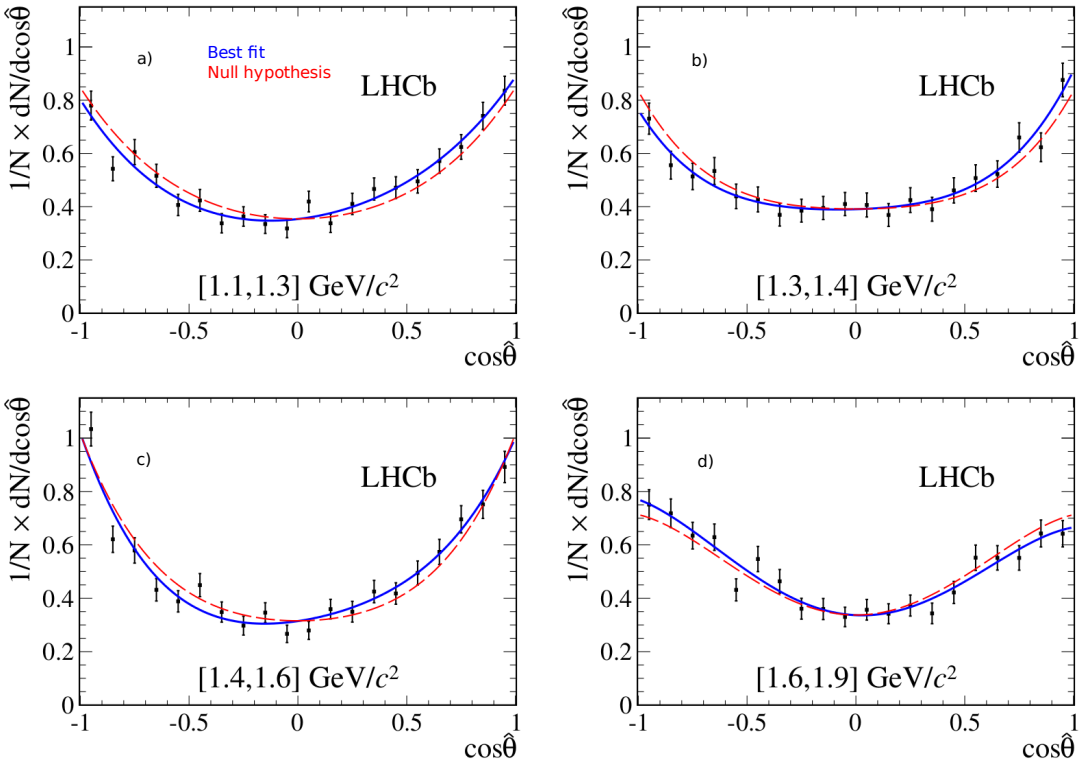
- The null hypothesis can be tested: is the photon polarized?

Photon polarization in $B^+ \to K^+\pi^-\pi^+\gamma$

LHCb: PRL 112 161801 (2014)



$A_{ud} \neq 0$, at $5.2\,\sigma$



The photon in $b \to s\gamma$ is polarized!

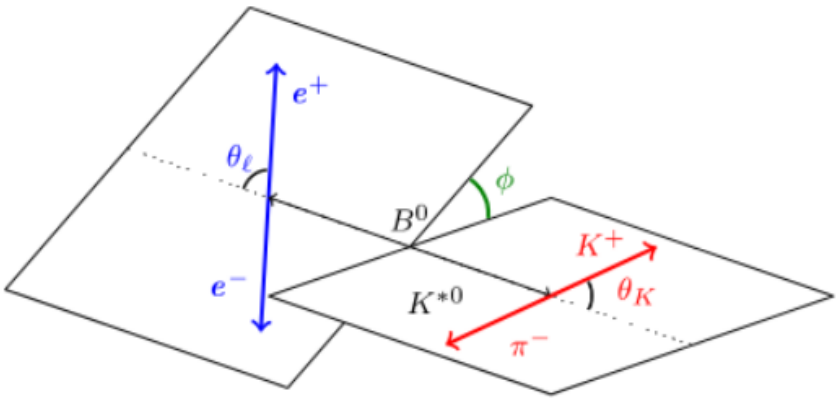
- To measure λ_γ, an amplitude analysis is needed
- Full amplitude analysis is ongoing

$B^0 \to K^{*0} e^+ e^-$ at the photon pole

Current best radiative constraint to C_7'

LHCb: JHEP 04 064 (2015)

- Angular analysis at the photon pole ($q^2 < 1$ GeV^2)
- Virtual photon decaying to $e^+ e^-$



Transverse asymmetries:

$$A_{\mathrm{T}}^{(2)}(q^2 \to 0) = \frac{2\mathrm{Re}(C_7 C_7'^*)}{|C_7|^2 + |C_7'|^2}$$

$$A_{\mathrm{T}}^{\mathrm{Im}}(q^2 \to 0) = \frac{2\mathrm{Im}(C_7 C_7'^*)}{|C_7|^2 + |C_7'|^2}$$

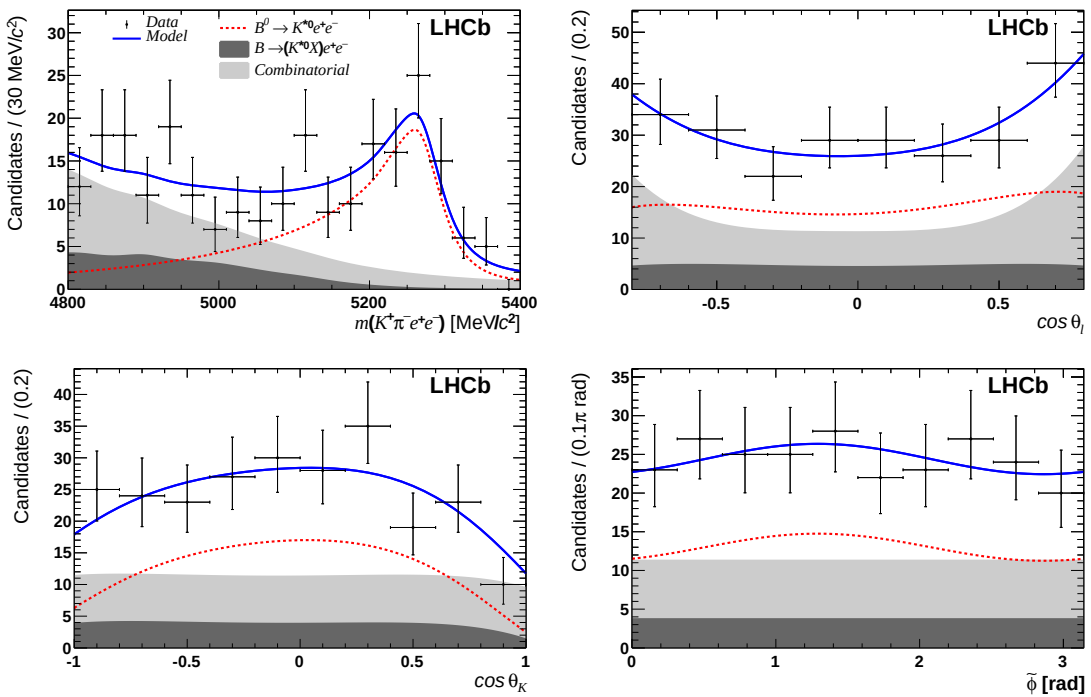
Three angles are involved

D.Becirevic and E.Schneider: J.Nucl Phys B 09 004 (2011)

$B^0 \to K^{*0} e^+ e^-$ at the photon pole

LHCb: JHEP 04 064 (2015)

- Reconstruction challenges:
  - Electrons are less efficient than muons
    About 150 signal events
  - Bremsstrahlung effects



Results compatible with SM

$$A_{\mathrm{T}}^{(2)} = -0.23 \pm 0.23 \pm 0.05$$

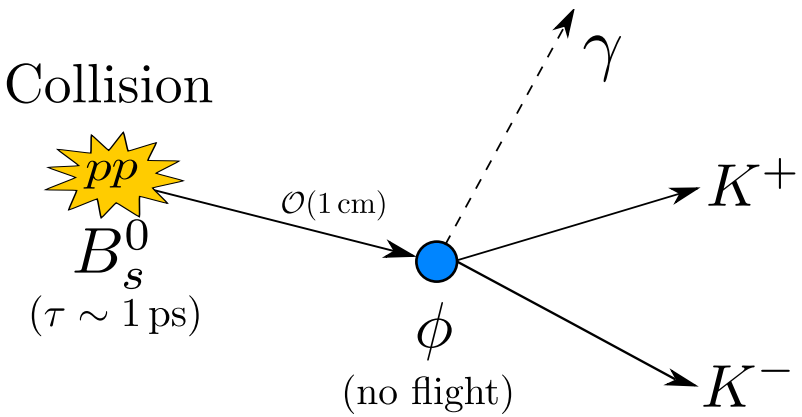
$$A_{\mathrm{T}}^{\mathrm{Im}} = +0.14 \pm 0.22 \pm 0.05$$

Time-dependent decay rate in $B_s^0 \to \phi\gamma$

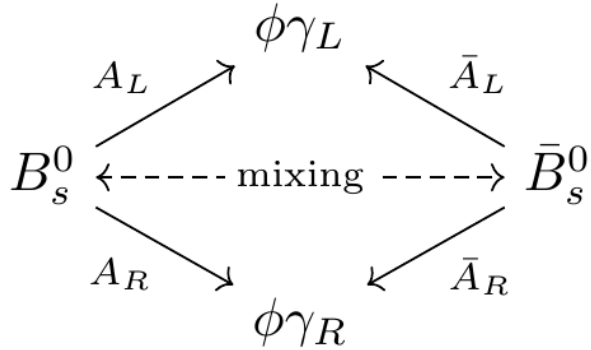
First measurement sensitive to photon polarization in B_s decays

LHCb: PRL 118 021801 (2017)

$B_s^0 \to \phi(\to K^+K^-)\gamma$ topology



Mixing/decay interference



$$\Gamma_{B_s^0,\bar{B}_s^0\to\phi\gamma}(t) \propto e^{-\Gamma_s t}[\cosh(\Delta\Gamma_s\, t/2) - A^{\Delta}\sinh(\Delta\Gamma_s\, t/2) \pm C\cos(\Delta m_s\, t) \mp S\sin(\Delta m_s\, t)]$$

Without identifying the B meson:

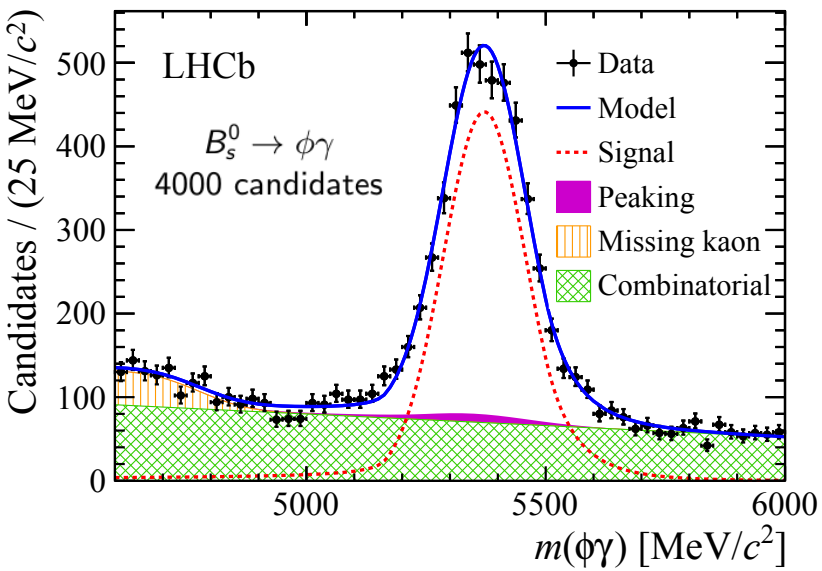
$$\Gamma_{(B_s^0+\bar{B}_s^0)\to\phi\gamma}(t) \propto e^{-\Gamma_s t}\left[\cosh(\Delta\Gamma_s t/2) - A^{\Delta}\sinh(\Delta\Gamma_s t/2)\right]$$

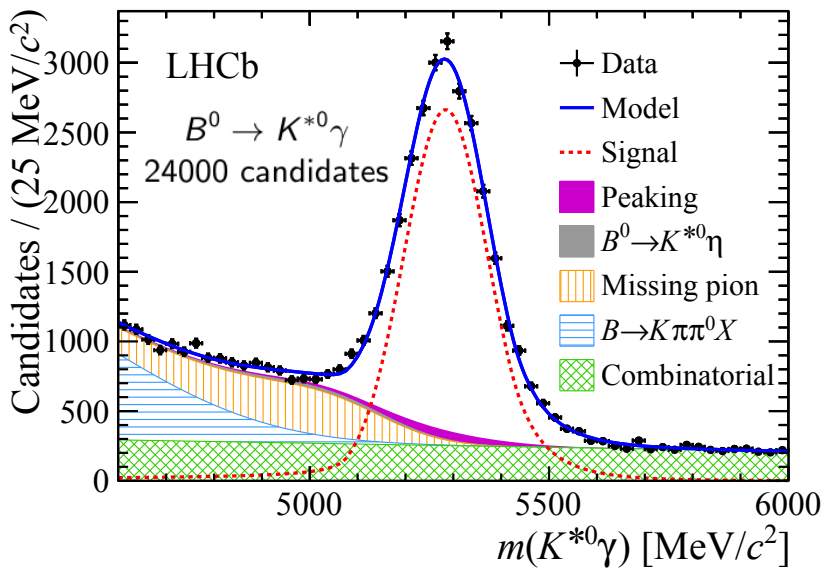
F.Muheim et al.: PRB 664 174 (2008)

Time-dependent decay rate in $B_s^0 \to \phi\gamma$

LHCb: PRL 118 021801 (2017)

- Signal and background yields extracted from mass distributions
- Modelling of the mass distributions:
  - Signal: double-tailed Crystal Ball
  - Combinatorial: First-order polynomial
  - Partially reconstructed: ARGUS convolved with a Gaussian
- $B^0 \to K^{*0}\gamma$ is used to control the decay time acceptance



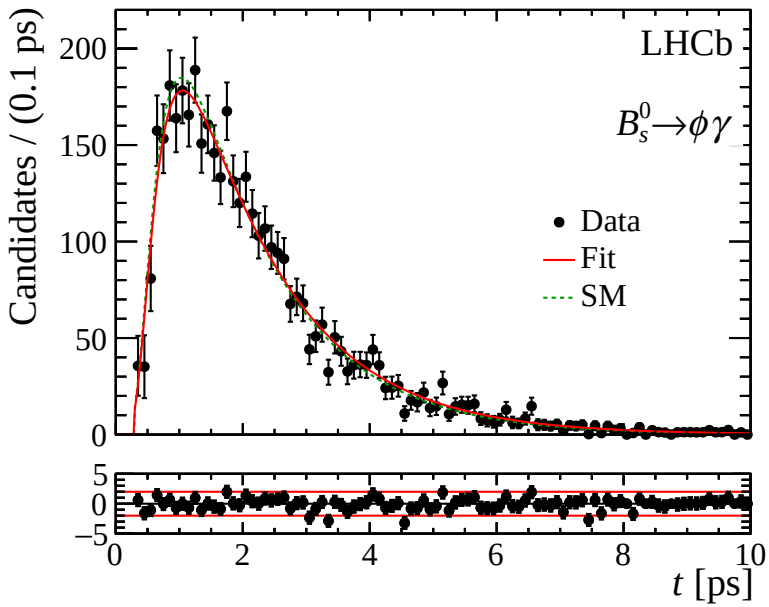


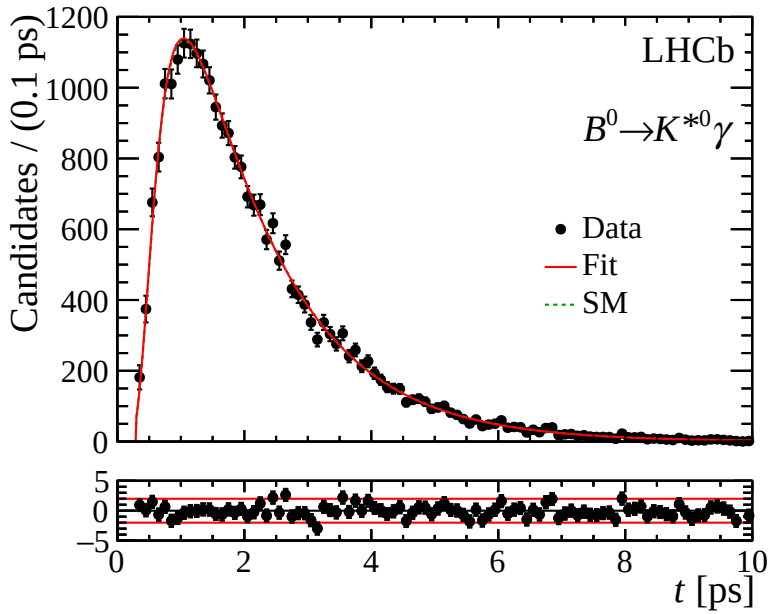
- $4\,000$ $B_s^0 \to \phi\gamma$ signal candidates

Time-dependent decay rate in $B_s^0 \to \phi\gamma$

LHCb: PRL 118 021801 (2017)

Unbinned fit

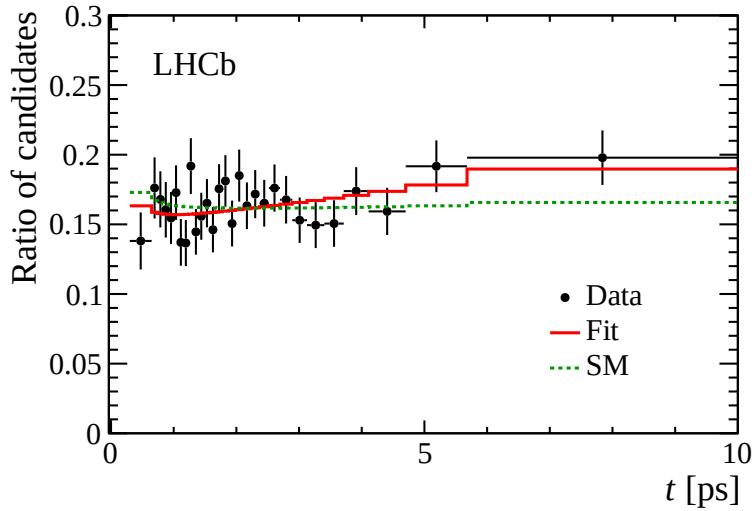




$$A^{\Delta} = -0.98\ ^{+0.46}_{-0.52}(\text{stat.})^{+0.23}_{-0.20}(\text{syst.})$$

Compatible with SM within 2σ

Ratio fit



Time-dependent decay rate in $B_s^0 \to \phi\gamma$

- A^Δ and S are sensitive to the photon polarization (and C_7'):

$$A^\Delta \simeq \frac{2\mathrm{Re}(e^{-i\phi_s}\,\mathcal{C}_7\,\mathcal{C}_7')}{|\mathcal{C}_7|^2+|\mathcal{C}_7'|^2} \qquad S \simeq \frac{2\mathrm{Im}(e^{-i\phi_s}\,\mathcal{C}_7\,\mathcal{C}_7')}{|\mathcal{C}_7|^2+|\mathcal{C}_7'|^2}$$

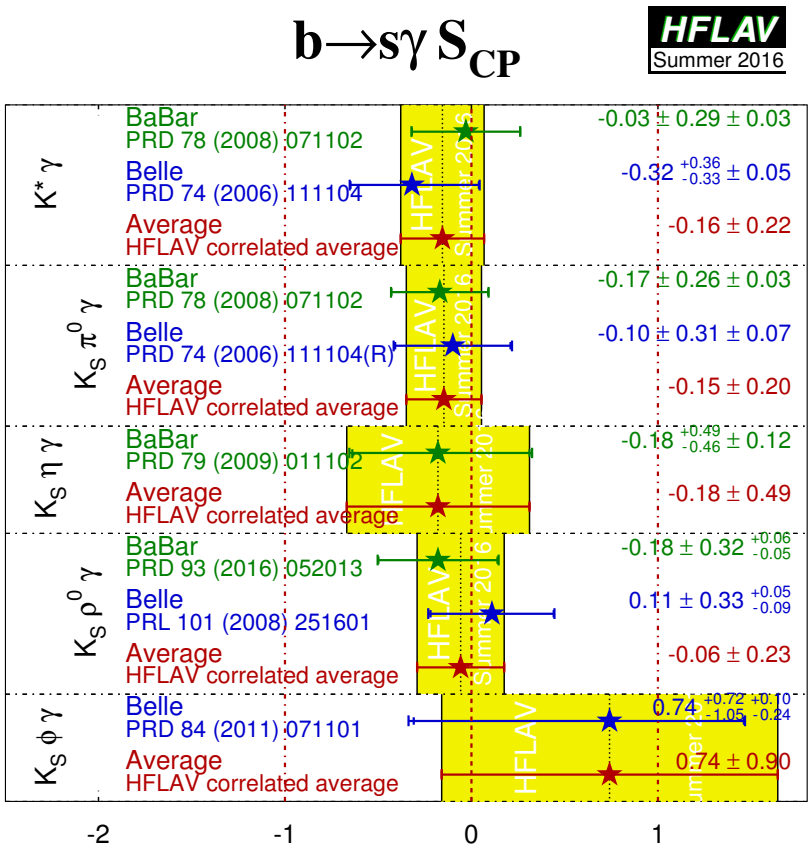
- SM prediction:

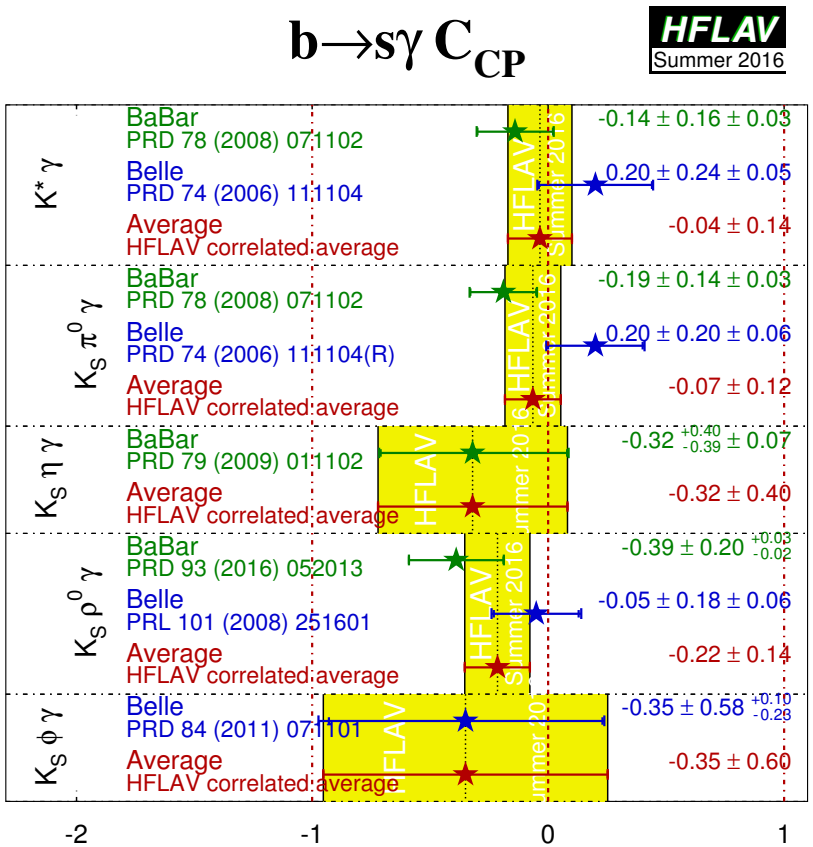
$$A^\Delta_{\mathsf{SM}} = 0.047^{+0.029}_{-0.025} \qquad S_{\mathsf{SM}} = 0 \pm 0.002$$

F.Muheim et al.: PRB 664 174 (2008)

Time-dependent decay rate in $B_s^0 \to \phi\gamma$

- At present, S_{CP} and C_{CP} only measured in the B_d system



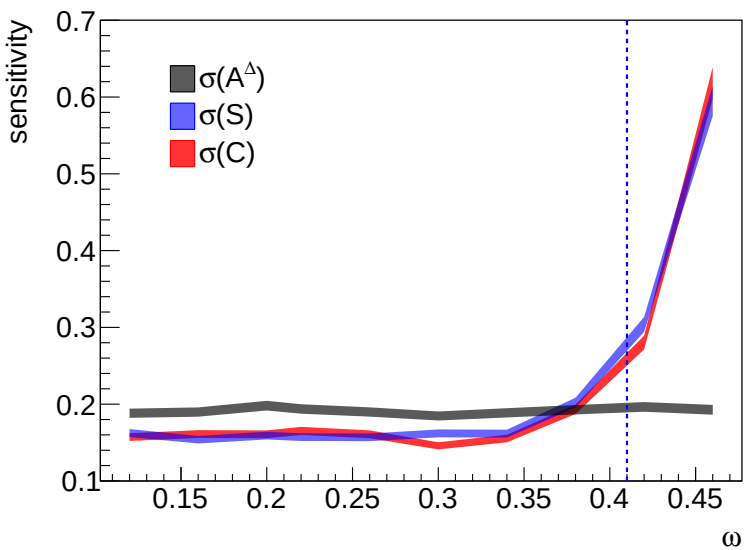


HFLAV latest averages: Eur. Phys. J. C77 895 (2017)

Time-dependent decay rate in $B_s^0 \to \phi\gamma$

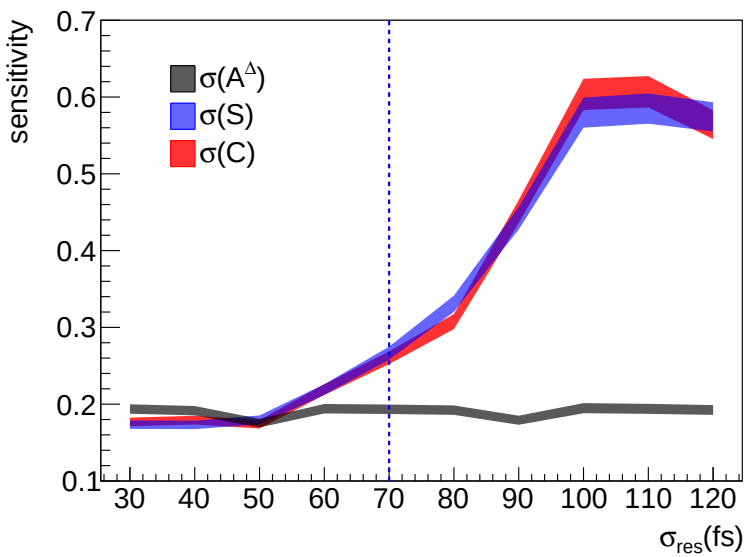
- The measurement of S_{CP} and C_{CP} is ongoing with Run1 data
- New challenges:
  - Flavour tagging (determine the flavour of $B_s^0/\bar{B}_s^0$)
  - Decay time resolution

Sensitivity vs mistag rate



$\omega = [0.36, 0.4]$

Sensitivity vs resolution

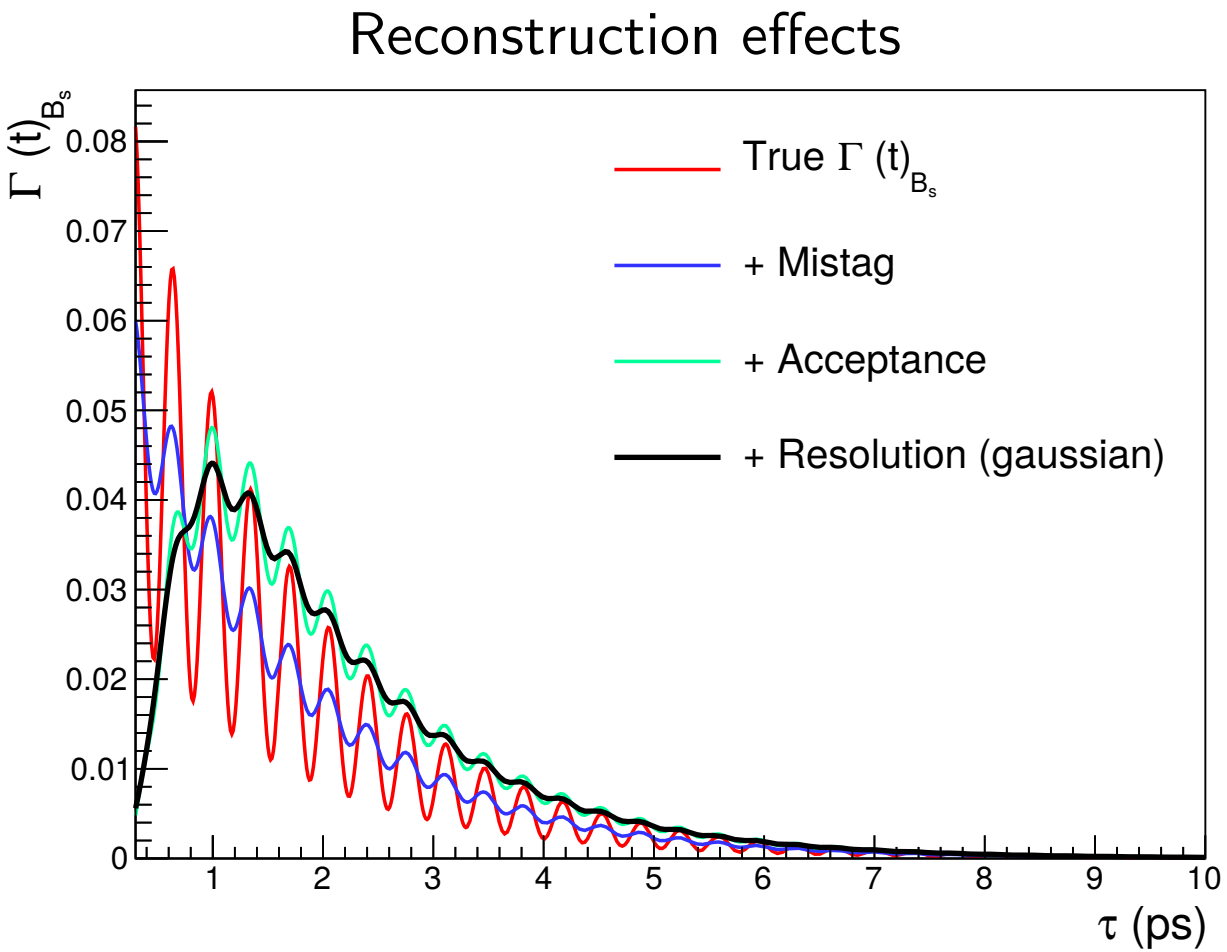


$\sigma_t \simeq [70, 80]$ fs^{-1}

Estimated values around the blue line

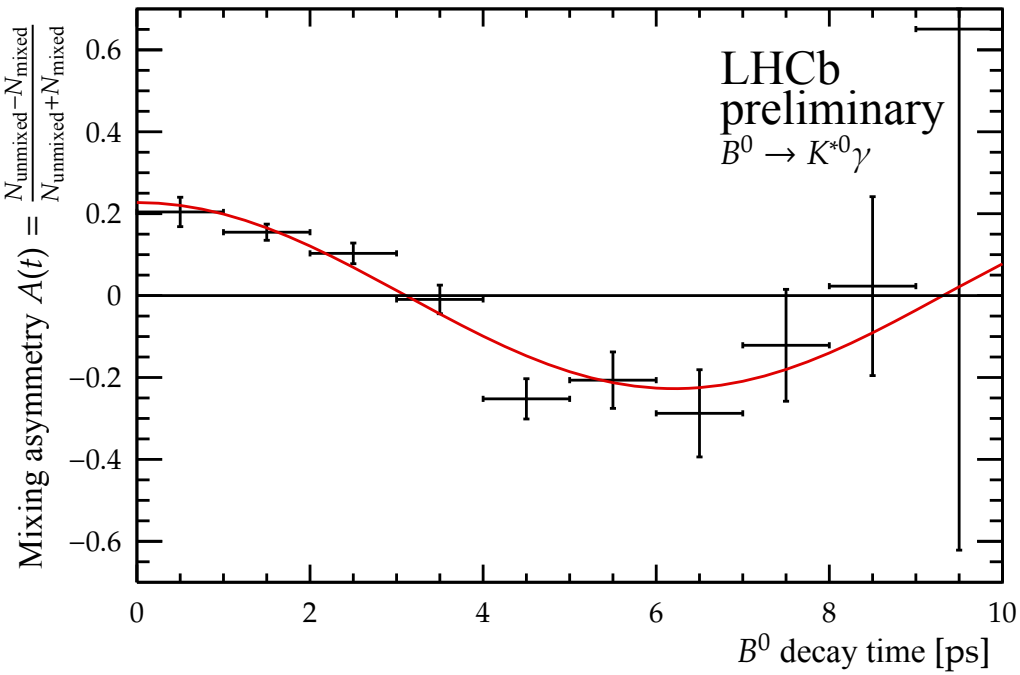
Time-dependent decay rate in $B_s^0 \to \phi\gamma$

- Oscillations in the decay time distribution



Time-dependent decay rate in $B_s^0 \to \phi\gamma$

- Testing the flavour tagging
- Mixing asymmetry in $B^0 \to K^{*0}\gamma$

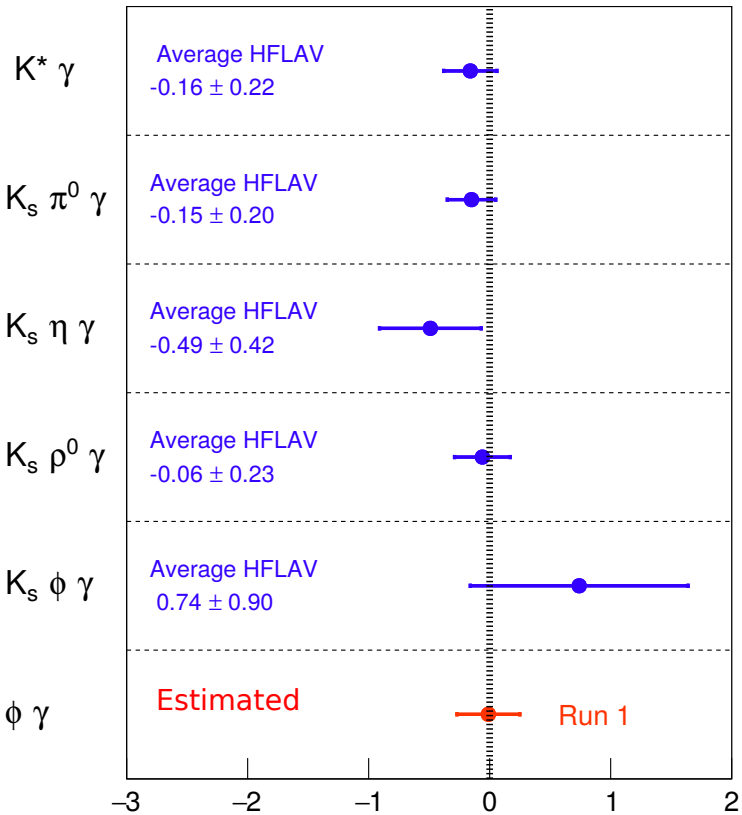


- First application of flavour tagging in radiative decays at LHCb

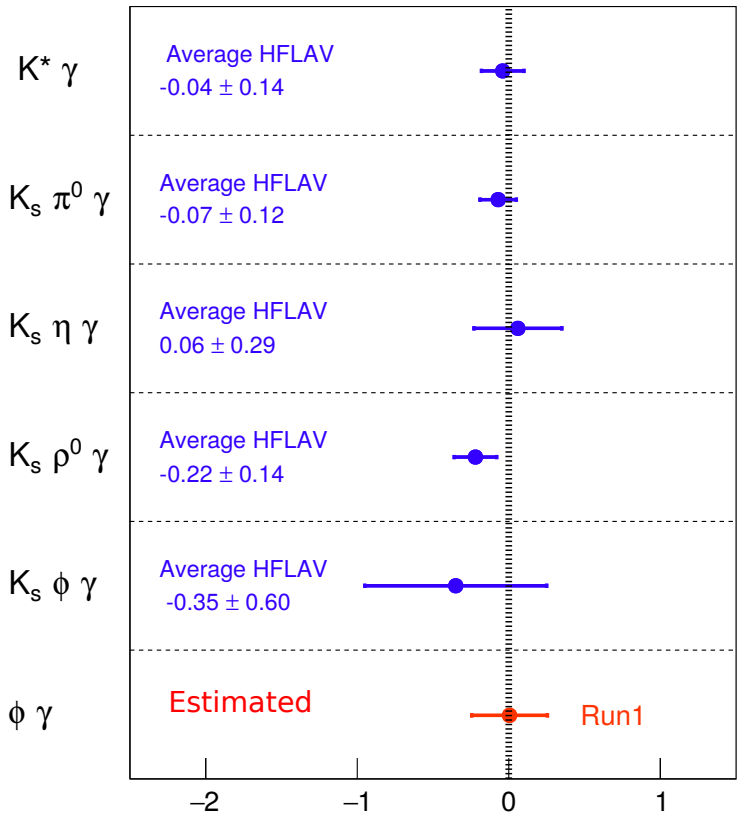
Reference: LHCb Flavour Tagging Plots

Time-dependent decay rate in $B_s^0 \to \phi\gamma$

S_{CP} measurements



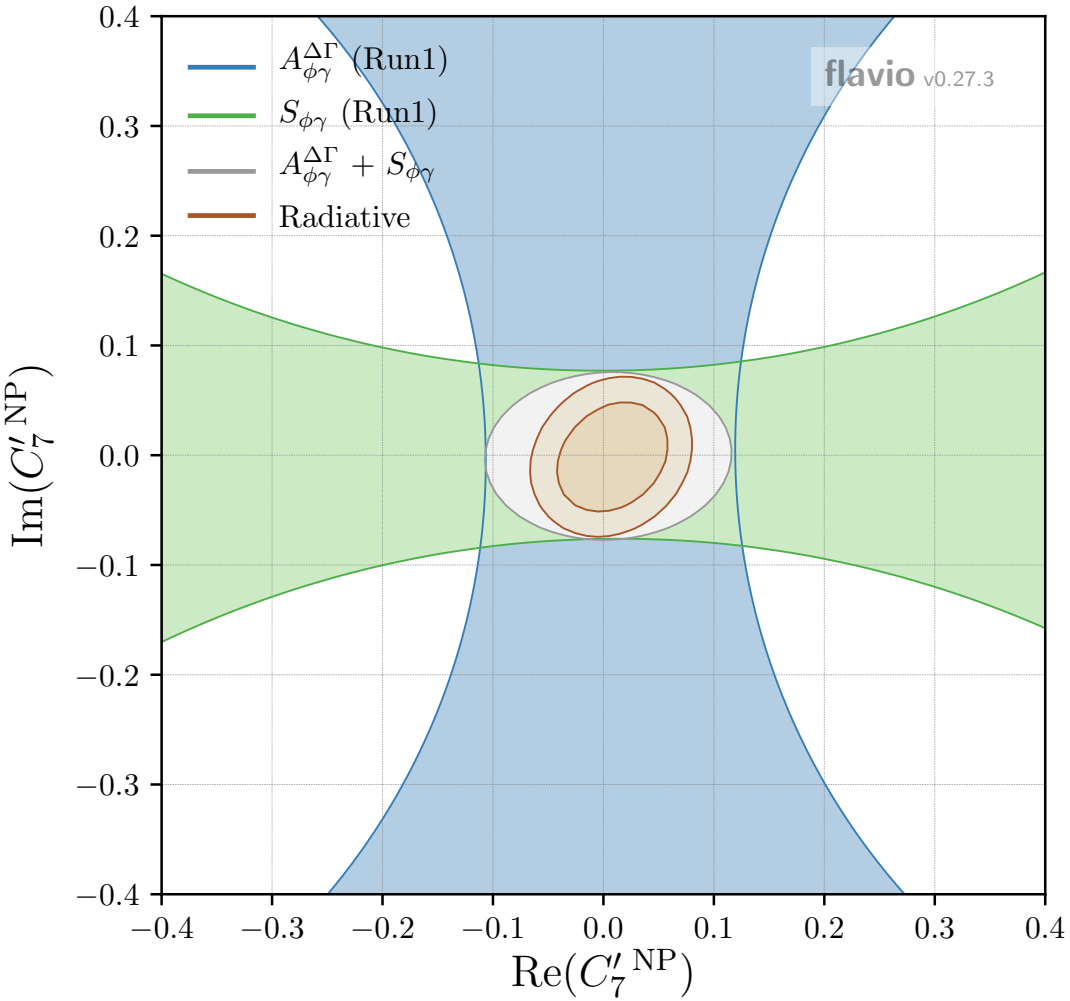
C_{CP} measurements



(*) Estimated sensitivity with LHCb Run1 data

Time-dependent decay rate in $B_s^0 \to \phi\gamma$

- Estimation of C_7' constraints with Run1 data
- Assuming $\sigma_{A^\Delta} \simeq \sigma_S \simeq 0.3$



b-baryon decays

- $\Lambda_b^0 \to \Lambda^0 \gamma$ has not been observed
  - Predicted $\mathcal{BR}$: 10^{-5} to 10^{-7}

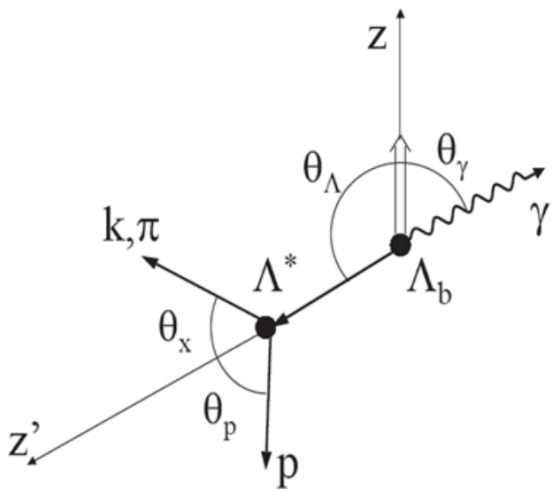
T.Mannel et al.: J.Phys G24 979-990 (1998)

- The angular distribution of $\Lambda_b^0 \to \Lambda^0 \gamma$ is sensitive to the photon polarization

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

$$\alpha_\gamma = \frac{C_7 - C_7'}{C_7 + C_7'}$$

$$\alpha_\Lambda = 0.642 \pm 0.013 \ \textit{[PDG]}$$

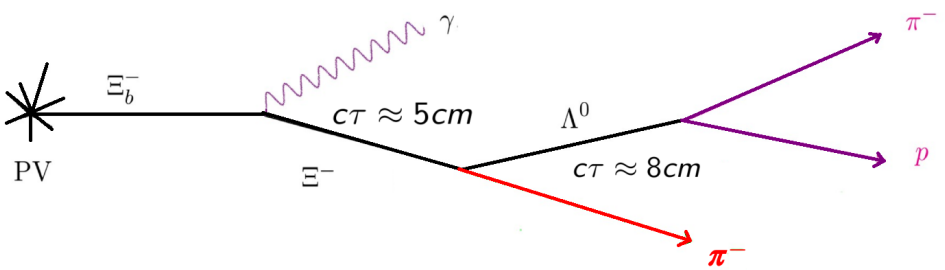


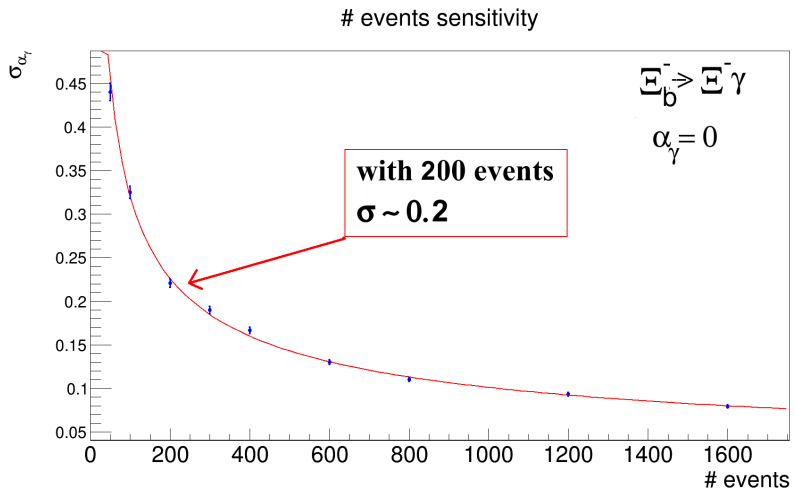
- Decay search with Run2 data in progress
- Reconstruction challenge: Λ^0 is a long-lived particle

L.Oliver et al.: PRD 82 117502 (2010)

b-baryon decays

- $\Xi_b^- \to \Xi^- \gamma$ has not been observed
  - Estimated: $\mathcal{BR}(\Xi_b^- \to \Xi^- \gamma) \sim \mathcal{BR}(\Lambda_b^0 \to \Lambda^0 \gamma)$





- Distribution depends on two angles:

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

$$\alpha_\Xi = -0.458 \pm 0.012 \text{ [PDG]}$$

- α_γ sensitivity similar to $\Lambda_b^0 \to \Lambda^0 \gamma$ decays

L.Oliver et al.: PRD 82 117502 (2010)

Summary

- Radiative decays are sensitive to the photon polarization
  - Allow to constrain the C_7' complex plane
- Potential to improve the current boundaries:
  - Analyses in progress using Run2 dataset of LHCb
  - Improvement of reconstruction and analysis techniques
  - New measurements are coming:
    $S(B_s^0 \to \phi\gamma)$, b-baryon decays...