Radiative *b*-hadron decays at LHCb

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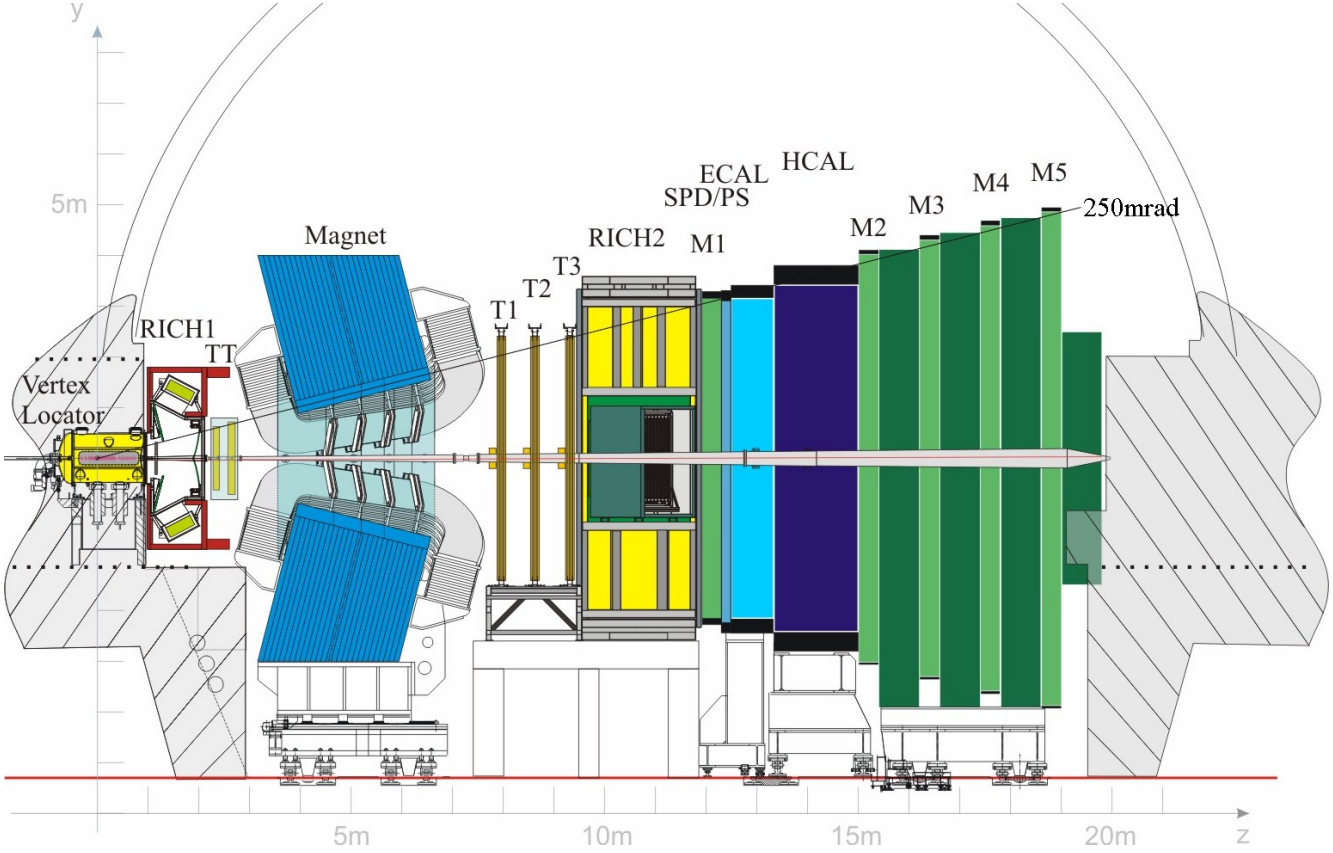
Outline

1. The LHCb detector
2. Photon polarization in radiative b-hadron decays
3. Observation of photon polarization in the $b \to s\gamma$ transition [PRL 112 (2014) 161801]
4. Angular analysis of the $B^0 \to K^{*0} e^+ e^-$ decay in the low-q^2 region [JHEP 04 (2015) 064]
5. **NEW!! First measurement of the photon polarization in radiative B_s^0 decays** [LHCB-PAPER-2016-034]
6. New Physics constraints
7. Summary

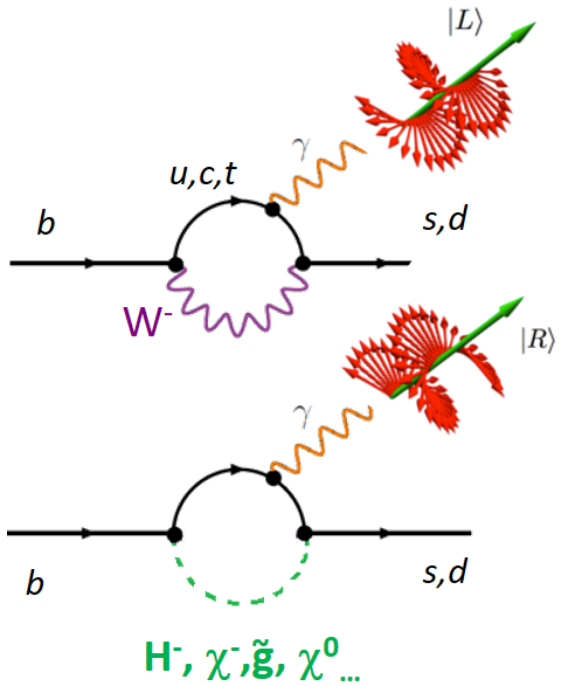
JINST 3 (2008) S080005



- Momentum resolution (charged hadrons): $\Delta p/p = 0.4 - 0.6\%$
- Photon resolution (ECAL): $\sigma/E \simeq 10\%/\sqrt{E} \oplus 1\%$
- Mass resolution with photons: 90 MeV/c^2
- Decay time resolution: 50 fs

Analyses shown in this presentation are performed with 3 fb^{-1} (Run 1 data)

- The $b \to s\gamma$ process is forbidden at tree level in the Standard Model (SM).
- Photons in such transitions are mainly **left-handed in the SM**, since the W boson couples to left-handed quarks
- New particles in the loop could enhance the right-handed contribution in New Physics models [Atwood et al. PRL79(97)185]



- Wilson coefficients $\mathcal{C}_7^{(\prime)}$ are related to left- (right)-handed polarized photons:

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{\rm tb} V_{\rm ts}^* \sum_i \Big(\underbrace{C_i \mathcal{O}_i}_{\text{left-handed}} + \underbrace{C_i' \mathcal{O}_i'}_{\text{right-handed}} \Big) + h.c.$$

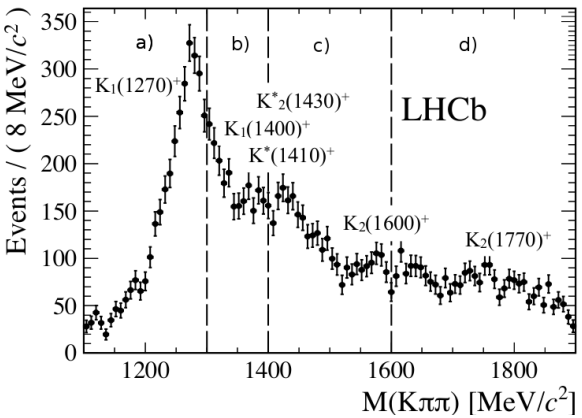
$$\mathcal{O}_7^{(\prime)} = \frac{e^2}{16\pi^2} m_b \left[\bar{s}\sigma_{\mu\nu} P_{R(L)} b\right] F^{\mu\nu}$$

$$\frac{C_7'}{C_7} \overset{\rm SM}{=} \mathcal{O}\left(\frac{m_s}{m_b}\right)$$

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

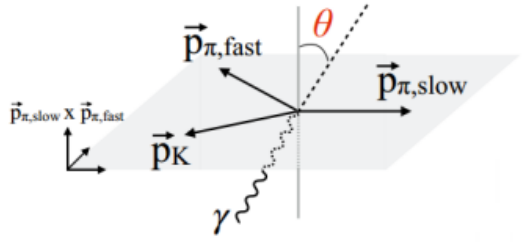
- Angular analysis of $B^+ \to K^+\pi^-\pi^+\gamma$ decays
- Several resonances contribute. Without amplitude analysis, only the **the null hypothesis (photon is not polarized) can be tested**, from the up-down asymmetry

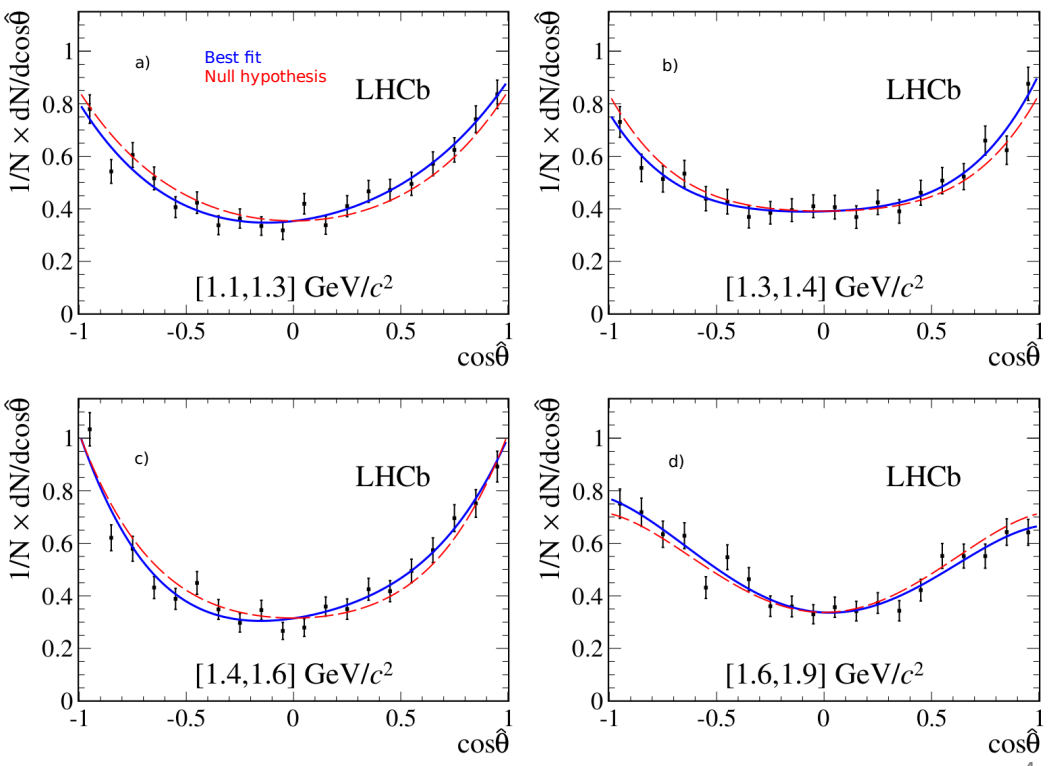
Angular distribution studied in four mass regions:



$$\frac{|\mathcal{C}_7'|^2 - |\mathcal{C}_7|^2}{|\mathcal{C}_7'|^2 + |\mathcal{C}_7|^2} \neq 0, \text{ at } 5.2\,\sigma$$

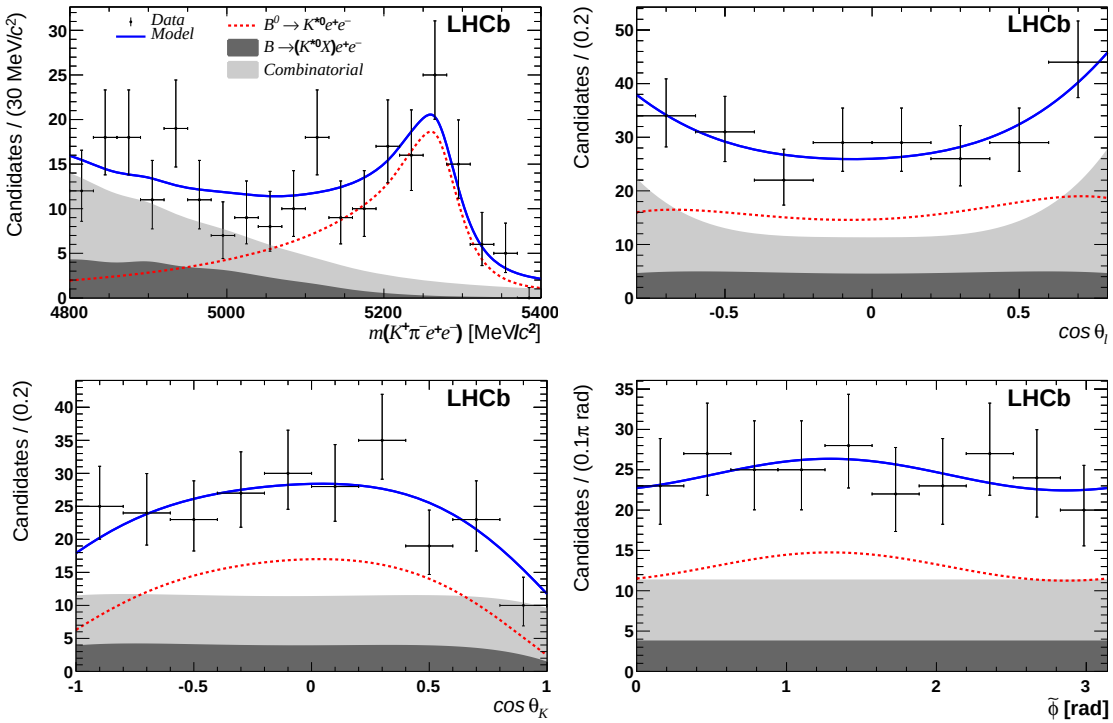
The photon is polarized!
(As predicted by the SM)



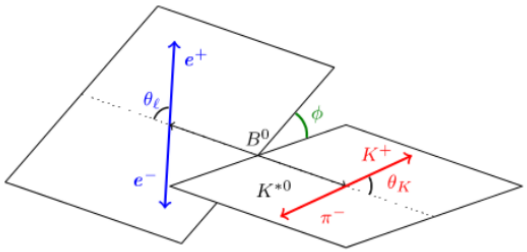


JHEP 04 (2015) 064

- Four dimensional fit to the mass and three angles



- Angular analysis at the **photon pole** ($q^2 < 1$ GeV^2)



q: invariant mass of e^+e^-

Observables related to the Wilson coefficients $\mathcal{C}_7^{(\prime)}$:

$$A_{\mathrm{T}}^{(2)}(q^2 \to 0) = \frac{2\,\mathrm{Re}\,(\mathcal{C}_7 \mathcal{C}_7^{\prime *})}{|\mathcal{C}_7|^2 + |\mathcal{C}_7^{\prime}|^2}$$

$$A_{\mathrm{T}}^{\mathrm{Im}}(q^2 \to 0) = \frac{2\,\mathrm{Im}\,(\mathcal{C}_7 \mathcal{C}_7^{\prime *})}{|\mathcal{C}_7|^2 + |\mathcal{C}_7^{\prime}|^2}$$

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

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

Compatible with SM ($\simeq 0$)

LHCB-PAPER-2016-034 (in preparation)

NEW!!

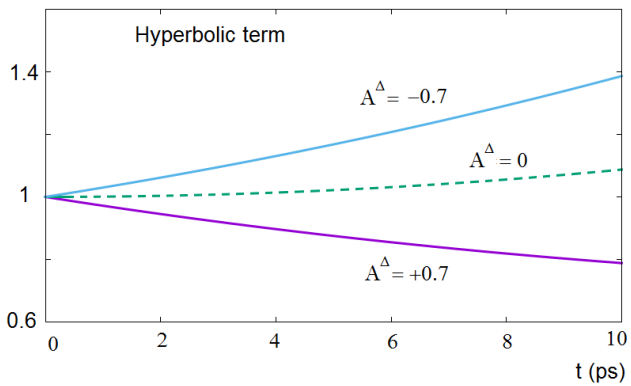
First measurement of the photon polarization in B_s^0 decays

- New measurement by LHCb using 3 fb^{-1} (Run 1 data)
- Photon polarization extracted from time-dependent decay rate in $B_s^0 \to \phi\gamma$, due to the interference of mixing and decay:

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

$\Delta\Gamma_s = 0.083 \pm 0.006$ ps^{-1} is the decay width difference of the B_s^0 system

[HFAG: arXiv:1412.7515]



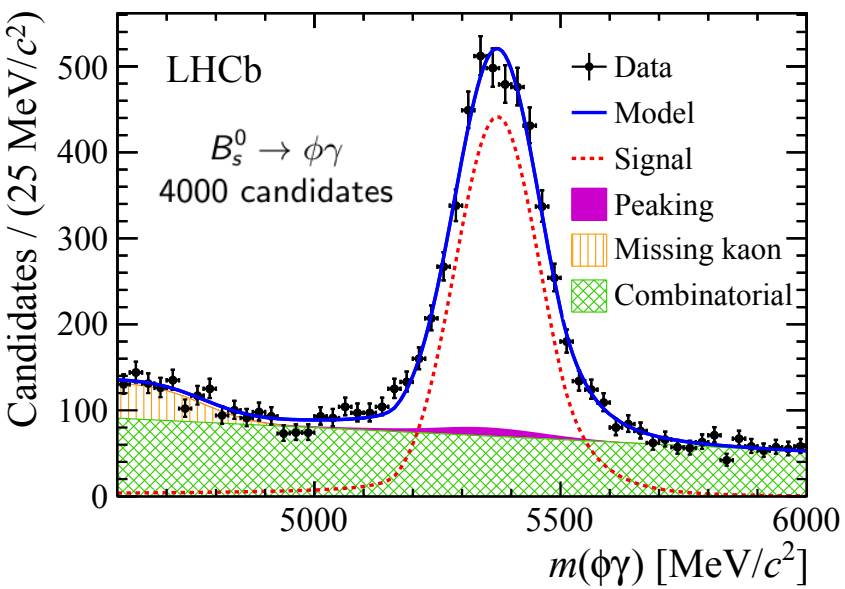
$$\mathcal{A}^{\Delta} \simeq \frac{2\,\mathrm{Re}\left(e^{-i\phi_s}\,\mathcal{C}_7\,\mathcal{C}_7'\right)}{|\mathcal{C}_7|^2 + |\mathcal{C}_7'|^2}$$

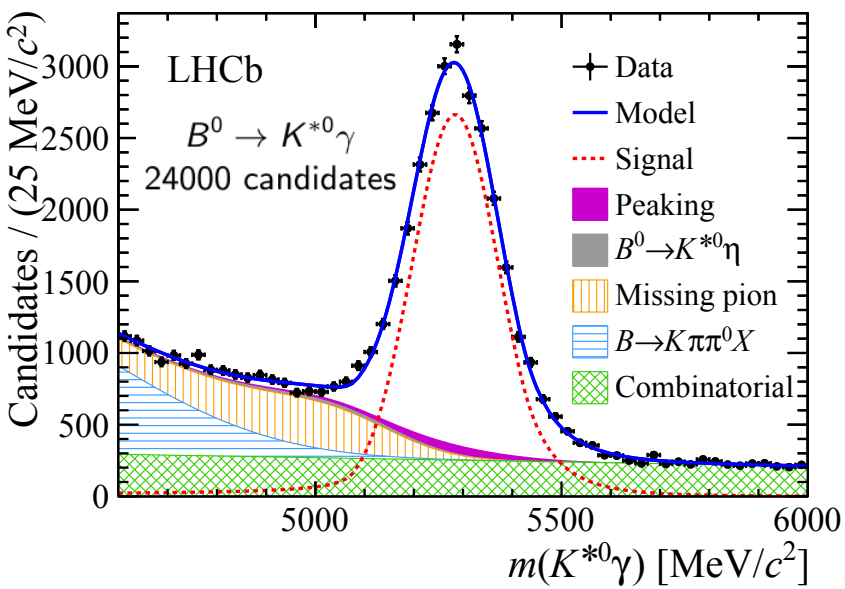
- SM prediction: $\mathcal{A}^{\Delta}_{\mathrm{SM}} = 0.047^{+0.029}_{-0.025}$ [PRB 664 (2008) 174]
- Due to the small $\Delta\Gamma_d$ in the $B^0/\bar{B}^0$ mixing, the decay rate of the $B^0 \to K^{*0}\gamma$ decay is an exponential:

$$\Gamma_{B^0 \to K^{*0}\gamma}(t) \propto e^{-\Gamma_d t}$$

Photon polarization in $B_s^0 \to \phi\gamma$: Mass fit

- The $B_s^0 \to \phi\gamma$ (signal) and $B^0 \to K^{*0}\gamma$ (control) decays are reconstructed, with two opposite sign hadrons ($\phi \to K^+K^-$ and $K^{*0} \to K^{\pm}\pi^{\mp}$) and a high-$E_T$ photon in the final state
- Signal and background yields extracted from mass distributions
- Modelling of the mass distributions:
  - **Signal**: modified Crystal Ball, with tails in both sides of the peak
  - **Combinatorial**: First-order polynomial
  - **Partially reconstructed**: ARGUS convolved with a Gaussian





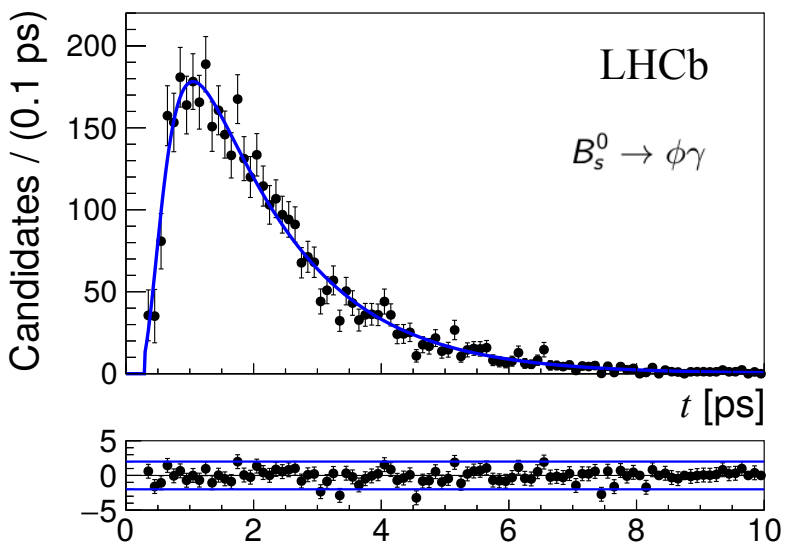
Photon polarization in $B_s^0 \to \phi\gamma$: Propertime fit

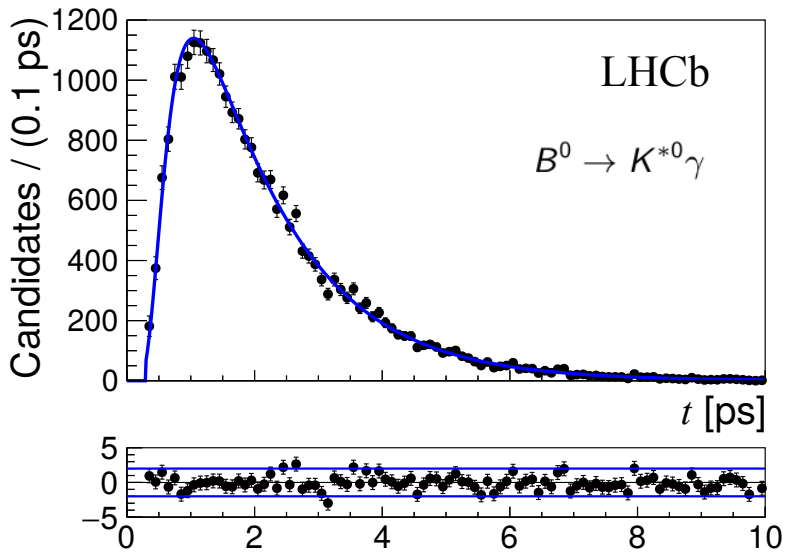
- Unbinned maximum likelihood fit to background-subtracted distributions, simultaneous to $B_s^0 \to \phi\gamma$ and $B^0 \to K^{*0}\gamma$ decay channels.

$$\Gamma(t) = \left[\Gamma(t') \times \epsilon(t')\right] * R(t, t')$$

  Physical rate $\Gamma(t')$ modified by the detector acceptance $\epsilon(t')$, convolved with resolution $R(t, t')$
- Acceptance extracted from simulation, and validated from $B^0 \to K^{*0}\gamma$ data:

$$\tau_{B_d}^{\text{fit}} = 1.524 \pm 0.013 \text{ ps} \quad \text{(compatible with World Average)}$$





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

Compatible with SM within 2σ

Photon polarization in $B_s^0 \to \phi\gamma$: Systematics

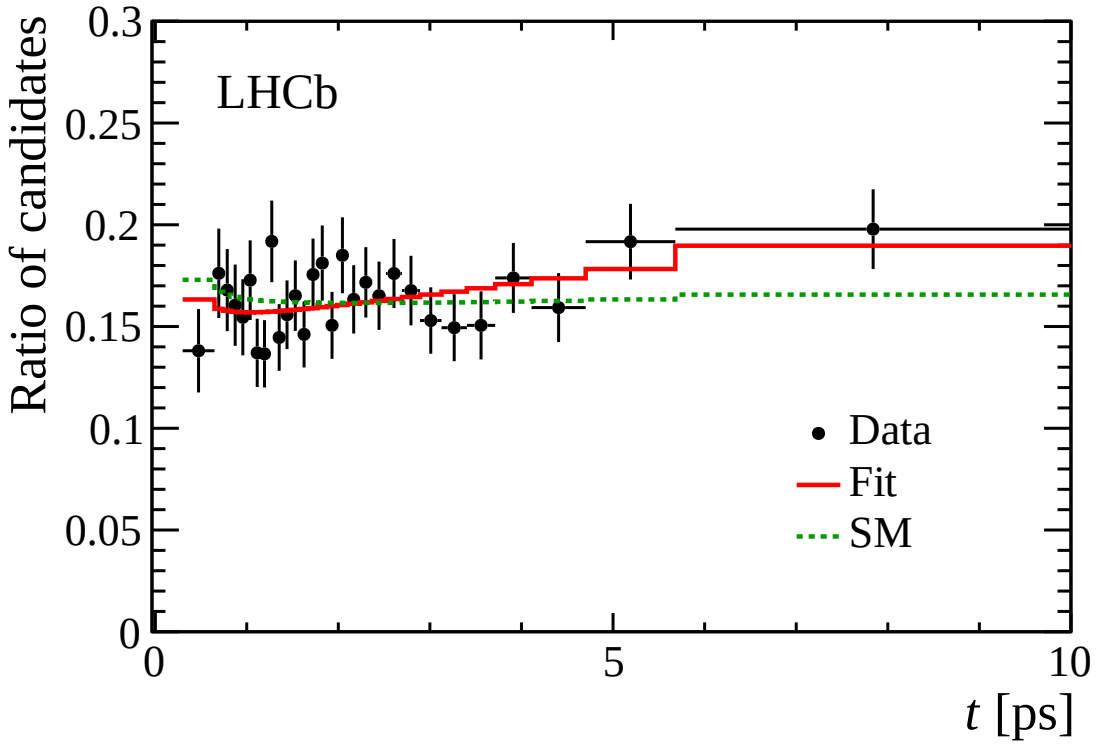
Table of systematic uncertainties:

Source	Pos. uncertainty	Neg. uncertainty
Correlations mass vs decay time in bkg	0.15	0.15
Peaking backgrounds	0.02	0.05
Mass modelling: signal	0.03	0.03
Mass modelling: combinatorial	0.07	0.07
Mass modelling: partial bkg	0.10	0.10
Acceptance function (from simulation)	0.13	0.05
Resolution function	0.01	0.01

- **Background subtraction** is the dominant contribution
- Followed by the **acceptance function** determination (size of the simulation samples)
- Negligible effect of the resolution

Photon polarization in $B_s^0 \to \phi\gamma$: Alternative fit

Binned ratio of $B_s^0 \to \phi\gamma$ over $B^0 \to K^{*0}\gamma$



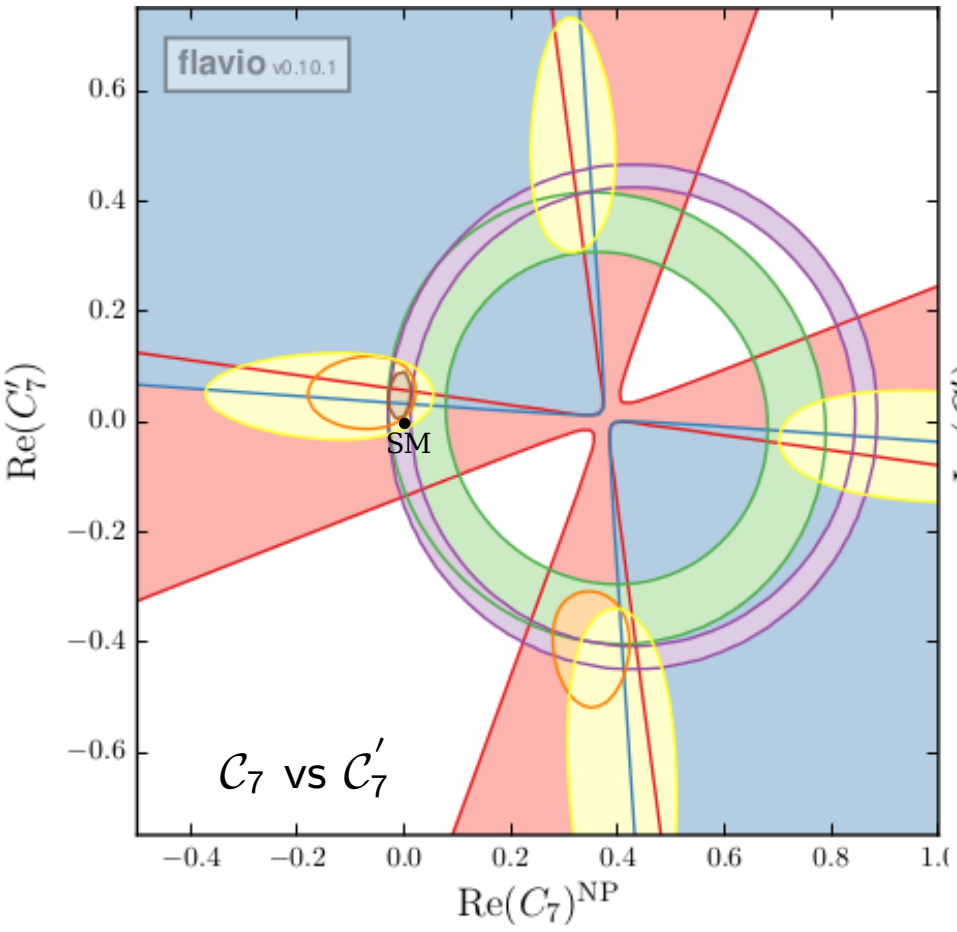
- Compatible results with the unbinned fit
- The shape is sensitive to the hyperbolic terms:

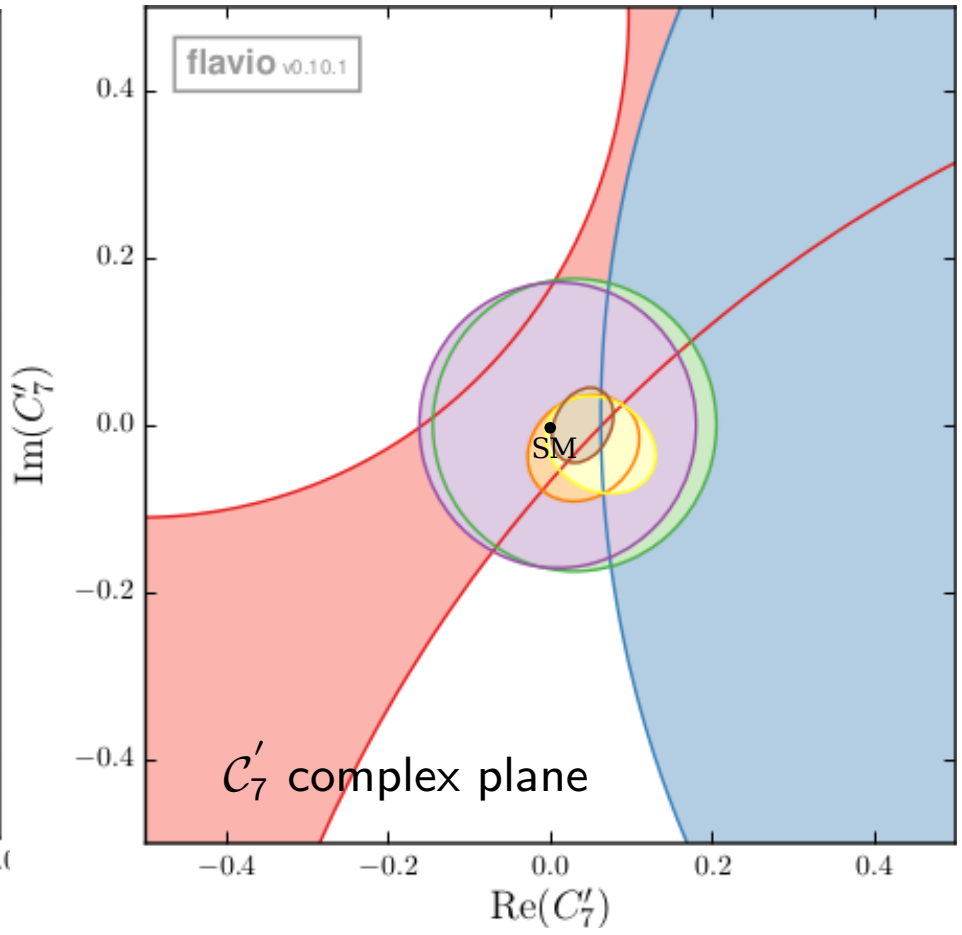
$$\sim \left[\cosh\left(\Delta\Gamma_s t/2\right) - \mathcal{A}^{\Delta} \sinh\left(\Delta\Gamma_s t/2\right)\right]$$

flavio: 10.5281/zenodo.50951

Putting together all the analyses sensitive to $b \to s\gamma$

68% CL contours





All combined

$\mathcal{A}^{\Delta}(B_s^0 \to \phi\gamma)$	[LHCB-PAPER-2016-034]
$\mathrm{ang}(B^0 \to K^{*0}e^+e^-)$	[LHCb: JHEP 04(2015)064]
$\mathrm{ang}(B^0 \to K^{*0}\mu^+\mu^-)$	[LHCb: JHEP 1602(2016)104]

$S_{K^*\gamma}$	[HFAG: arXiv:1207.1158]
$\mathrm{BR}(B \to X_s\gamma)$	[HFAG: arXiv:1207.1158]
$\mathrm{BR}(B_s^0 \to \phi\gamma)$	[LHCb: Nucl.Phys. B867(2013)1-18]
	[Belle: PRD91 1(2015)011101]

Summary

- Analyses reported with the full Run 1 data of 3 fb^{-1} collected by the LHCb experiment

1. First observation of the photon polarization in $b \to s\gamma$ decays, with $B^+ \to K^+\pi^-\pi^+\gamma$
2. Angular analysis of $B^0 \to K^{*0}e^+e^-$
3. First measurement of the photon polarization in B_s^0 decays **NEW**:
   - Time-dependent decay rate of $B_s^0 \to \phi\gamma$
   - $\mathcal{A}^{\Delta} = -0.98\,^{+0.46}_{-0.52}(\text{stat.})^{+0.23}_{-0.20}(\text{syst.})$
   - Compatible with the SM expectation within 2σ

- Constraints compatible so far with the SM
- More than 1 fb^{-1} already collected in Run 2 $\to$ updates with more statistics in progress!