Photon polarisation in $B_s^0 \to \phi\gamma$ at LHCb

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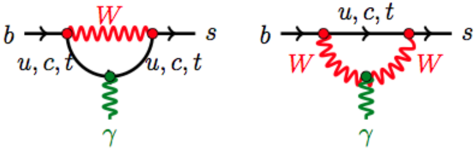
Photon polarisation in $b \to s\gamma$ transition

- Transitions driven by FCNC represent pure quantum effects within the SM



- Loop-driven B decays are more sensitive to the presence of New Physics beyond SM.
- The SM photon in $b \to s\gamma$ is predominantly left-handed

$$\bar{s}\Gamma_{\mu}^{b\to s\gamma} b = \frac{e}{(4\pi)^2}\frac{g^2}{2M_W^2} V_{ts}^* V_{tb} F_2 \bar{s} i \sigma_{\mu\nu} q^{\nu} \left(m_b \frac{1+\gamma_5}{2} + \quad m_s \frac{1-\gamma_5}{2} \right) b$$

$$b_R \to s_L \gamma_L \qquad b_L \to s_R \gamma_R$$

- The right-handed contribution can be significantly enlarged due to new physics.

Determination of the Wilson coefficient C_7'

- The effective electroweak Hamiltonian relevant to $b \to s$ transitions in SM:

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha_e}{4\pi} \sum_i \mathcal{C}_i(\mu_s) \mathcal{O}_i(\mu_s)$$

  - $\mathcal{O}_7^{(\prime)}$ are the electro-magnetic penguin operators:

$$\mathcal{O}_7 = \frac{m_b}{e} \bar{s} \sigma^{\mu\nu} \frac{1+\gamma_5}{2} b F_{\mu\nu}, \qquad \mathcal{O}_7' = \frac{m_b}{e} \bar{s} \sigma^{\mu\nu} \frac{(1-\gamma_5)}{2} b F_{\mu\nu}$$

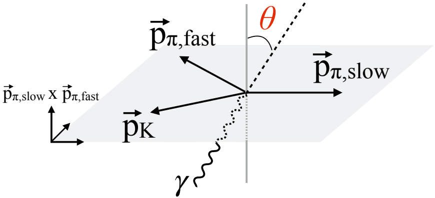
  - **Wilson coefficient $\mathcal{C}_7'$** is suppressed by $\mathcal{O}(m_s/m_b)$ due to the left-handedness of the charged-current interaction.
- Methods most sensitive to the photon polarisation provide complementary information:
  - The time-dependent CP-asymmetry in $B_{(s)} \to f^{CP}\gamma$: $\mathbf{B_s^0} \to \phi\gamma$, $B^0 \to K_S^0 \pi^0 \gamma$
  - Angular correlations among the three-body decay products of the excited kaons in $B \to K_{\text{res}}(P_1 P_2 P_3)\gamma$: $\mathbf{B} \to \mathbf{K_1}(\mathbf{K}\pi\pi)\gamma$, $B \to \phi K \gamma$
  - Transverse asymmetry in $\mathbf{B^0} \to \mathbf{K^*(892)^0 e^+ e^-}$

Photon polarisation in $B^+ \to K^+_{\text{res}}(K\pi\pi)\gamma$

- The photon polarisation parameter in $B \to K_{\text{res}}\gamma$ is given by

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

- The up-down asymmetry is proportional to the photon polarisation λ_γ.



$$\mathcal{A}_{\text{up-down}} \equiv \frac{\int_0^1 d\cos\theta \frac{d\Gamma}{d\cos\theta} - \int_{-1}^0 d\cos\theta \frac{d\Gamma}{d\cos\theta}}{\int_{-1}^1 d\cos\theta \frac{d\Gamma}{d\cos\theta}}$$

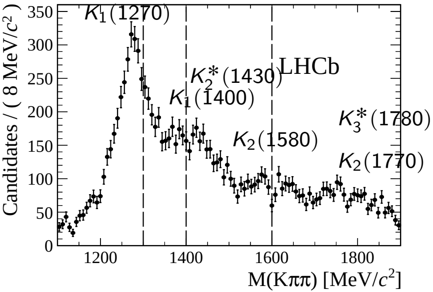
$$= \frac{3}{4}\lambda_\gamma \frac{<\text{Im}(\hat{n}\cdot(\vec{\mathcal{J}} \times \vec{\mathcal{J}}^*))>}{<|\vec{\mathcal{J}}|^2>}$$

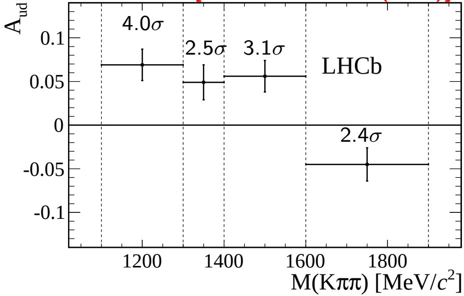
$\mathcal{J}$ is the helicity amplitude of $K^+_{\text{res}} \to K\pi\pi$.

- To determine λ_γ
  - $Im[\vec{n}\cdot(\vec{\mathcal{J}} \times \vec{\mathcal{J}}^*)]$ cannot be zero, i.e. $\mathcal{J}$ contains more than one amplitude and a non-vanishing relative phase.
  - A precise information on the helicity amplitude $\mathcal{J}$ is needed.

Photon polarisation in $B^+ \to K^+_{\text{res}}(K\pi\pi)\gamma$

[PRL 112, 161801 (2014)]



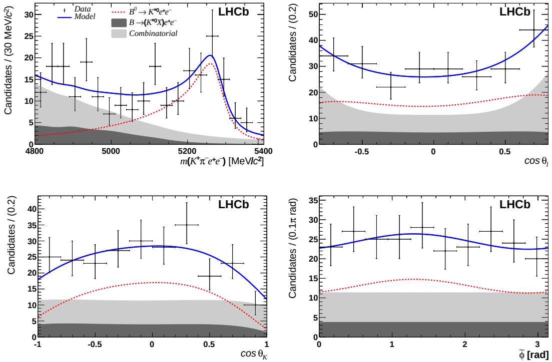


- 13876±153 selected $B^\pm \to K^\pm\pi^\mp\pi^\pm\gamma$ candidates with 3 fb^{-1} data at LHCb.
- A combined significance with respect to the non-polarisation scenario is extracted with $\mathcal{A}_{\text{ud}}$ different from zero at 5.2σ.
- **First observation of photon polarisation in $b \to s\gamma$ transition!**
- Ungoing study to understand detailed strong interactions of the K_{res} decay to extract the photon polarisation.

Angular analysis of $B^0 \to K^* e^+ e^-$ at low-q^2

- 4D fit to $m(K^+\pi^-e^+e^-)$ and three angles to extract the four observables F_L, A_T^{Re}, $A_T^{(2)}$ and A_T^{Im} with 124 events:

[JHEP04(2015)064]



- Angular observables firstly measured in an q^2 range [0.0020,1.120] $\mathrm{GeV}^2/\mathrm{c}^2$:

$A_T^{(2)}(q^2 \to 0) = \frac{2\mathrm{Re}(C_7 C_7'^*)}{|C_7|^2+|C_7'|^2}$: **-0.23±0.23±0.05** F_L **(longitudinal): 0.16±0.06±0.03**

$A_T^{\mathrm{Im}}(q^2 \to 0) = \frac{2\mathrm{Im}(C_7 C_7'^*)}{|C_7|^2+|C_7'|^2}$: **+0.14±0.22±0.05** $A_T^{\mathrm{Re}} = \frac{4}{3} A_{FB}/(1-F_L)$: **+0.10±0.18±0.05**

Photon polarisation in $B_s^0 \to \phi\gamma$

- Untagged decay time in $B_s^0 \to \phi\gamma$ [LHCb-PUB-2009-029]:

$$\Gamma_{B_s^0(\overline{B}_s^0)\to\phi\gamma} \propto e^{-\Gamma_{B_s^0} t}\left(\cosh\frac{\Delta\Gamma_s t}{2} - A^{\Delta}\sinh\frac{\Delta\Gamma_s t}{2}\right)$$

where

$$A^{\Delta} \approx \sin 2\psi \cos\varphi_s \ (\varphi_s \text{ is the } B_s \text{ mixing phase})$$

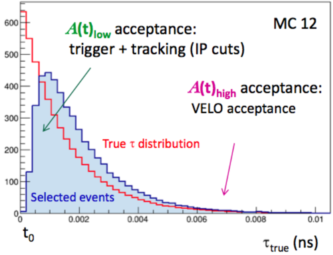
- ψ is given by the fraction of "wrongly"-polarized photons and defined as

$$\tan\psi = \left|\frac{A(\overline{B}_s^0 \to \phi\gamma_R)}{A(\overline{B}_s^0 \to \phi\gamma_L)}\right|$$

- Standard Model: $A^{\Delta}_{\text{SM}} = 0.047 \pm 0.025 \pm 0.015$ [Muheim et al. PLB664(2008)174]
- Left-Right Symmetric model (LRSM): $A^{\Delta}_{\text{LRSM}} \sim 0.7$

Extract A^Δ from lifetime study

- **Acceptance** $A(t)_{\text{low}} \times A(t)_{\text{high}}$: trigger, tracking, selection and reconstruction requirements



- Parameterization of the acceptance using function $A(t)$:

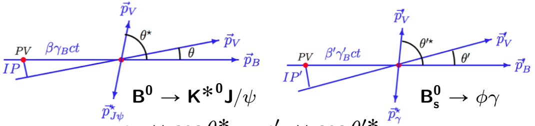
$$A(t) = \underbrace{\frac{[a(t-t_0)]^n}{1+[a(t-t_0)]^n}}_{A(t)_{\text{low}}} \times \underbrace{e^{-\delta\Gamma t}}_{A(t)_{\text{high}}}$$

- Key in the photon polarization measurement;
- Need to be precisely determined/controlled.

- **Background**: subtracted with sPlot technique based on the B mass fit
- **Resolution**: dominated by the photon momentum, from Monte Carlo
- **The blinding method**: add random number to result, i.e. A^Δ value

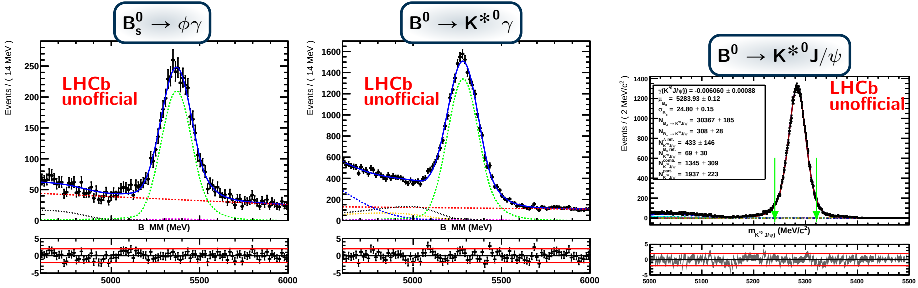
Acceptance from control channels

- Similar radiative decay: $B^0 \to K^{*0}\gamma$
  - Similar topology, same trigger for the photon, similar resolution, large statistics
  - Large background
  - Avoid selection cuts to introduce difference in acceptance
- Background free channel: $B^0 \to K^{*0} J/\psi$
  - Clean sample with low background and large statistics
  - An unbiased selection with B decay vertex reconstructed with K^* decay daughters and dimuon trigger used
  - A 2D kinematical reweighting: helicity angle $\cos\theta_H$ and $p_V \cdot \cos\theta$ and then scale the related variables by a constant scaling factor



$$p_V \times \cos\theta^* = p'_V \times \cos\theta'^*$$

Background subtraction



- SPlot technique for $B^0 \to K^{*0}\gamma$ and $B_s^0 \to \phi\gamma$
- Tight signal mass range from 5240 to 5320 MeV/c^2 for background free channel $B^0 \to K^* J/\psi$
- Number of signal events **[LHCb unofficial]**:

$B_s^0 \to \phi\gamma$	$B^0 \to K^{*0}\gamma$	$B^0 \to K^{*0}J/\psi$
3595±88	23356±323	30367±185

Fitting procedures

$B_s^0 \to \phi\gamma$
(∼3600)

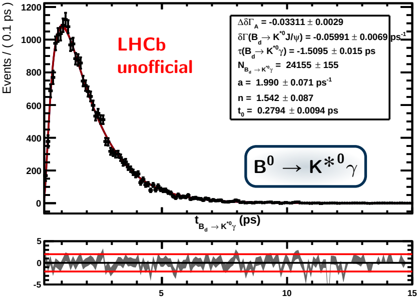
$B^0 \to K^{*0}\gamma$
(∼24000)

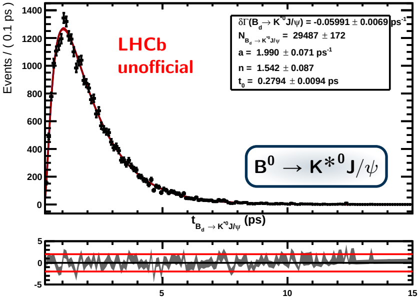
$B^0 \to K^{*0}J/\psi$
(∼30000)

- Two different fitting procedures developed:
  - "Direct fit": an unnbinned simultaneous maximum likelihood fit
  - "Ratio fit": a binned ratio fit
- Good compatibility between two fitting procedures shown by toy studies.

Fitting procedure: “Direct Fit”

- Unbinned simultaneous ML fit to $B_s^0 \to \phi\gamma$ and $B^0 \to K^{*0}\gamma$ and/or $B^0 \to K^{*0}J/\psi$.
- A validation by extracting τ_{B^0} from $B^0 \to K^{*0}\gamma$ and $B^0 \to K^{*0}J/\psi$:
  - $B^0 \to K^{*0}\gamma$ as signal channel with τ_{B^0} free;
  - $B^0 \to K^{*0}J/\psi$ as control channel with τ_{B^0} fixed to PDG value.





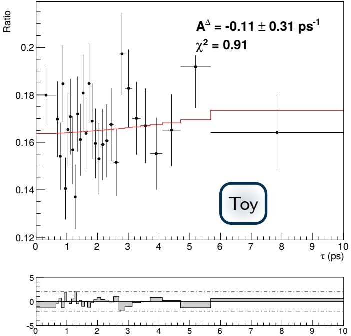
- Fitted $\tau_{B^0} = 1.511 \pm 0.014$ ps which is consistent with the world average value 1.519 ps [arXiv:1412.7515].

Fitting procedure: "Ratio fit"

- Fit on the ratio of the $B_s^0 \to \phi\gamma$ and $B^0 \to K^{*0}\gamma$ lifetimes:

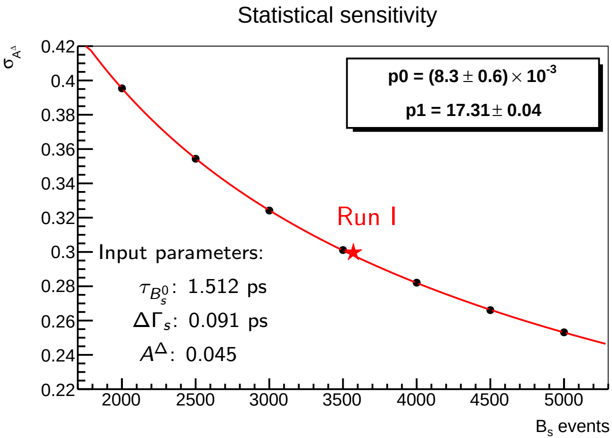
$$R_i^{\text{exp}}(t) = \frac{\int_{t^i_{\text{low}}}^{t^i_{\text{high}}} dt \mathcal{A}_{\phi\gamma}\, e^{-t/\tau_{B_s^0}} \left\{\cosh\frac{\Delta\Gamma_s t}{2} - A^{\Delta} \sinh\frac{\Delta\Gamma_s t}{2}\right\}}{\int_{t^i_{\text{low}}}^{t^i_{\text{high}}} dt \mathcal{A}_{K^*\gamma}\, e^{-t/\tau_{B^0}}},$$

  where $\tau_{B_s^0}$, τ_{B^0}, $\Delta\Gamma_s$ are from HFAG.
- The uncertainties due to topology and kinematics significantly reduced because of the similarities between the two radiative channels.



Measurement of A^{Δ}: still blinded

- Analysis of Run I data ($\sim$3600 reconstructed $B_s^0 \to \phi\gamma$ events) in progress.
- Expected A^{Δ} sensitivity of $\sim$0.3 (statistically limited).



Summary

- LHCb provides a very good platform to measure the photon polarisation in radiative B decays.
  - The emitted photons are firstly observed to be polarised in the study of $B^{\pm} \to K^{\pm}\pi^{\mp}\pi^{\pm}\gamma$ decay with 3 fb^{-1} data sample but further amplitude analysis needed to isolate different resonances.
  - Angular observables are firstly measured in an effective q^2 range [0.0020,1.120] GeV^2/c^4 in $B^0 \to K^* e^+ e^-$ and results are consistent with SM predictions.
  - The photon polarisation measurement in the decay $B_s^0 \to \phi\gamma$ is in progress.
- Combination of the three will put strong constraint on the short-distance $C_7^{(\prime)}$ coefficients in a model-independent way.
- But the measurements are statistically limited so far, we will be able to measure the photon polarisation with high precision in the future.