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

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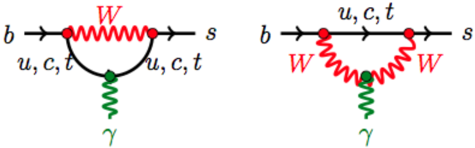
(On behalf of LHCb Collaboration)

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

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

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

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

Photon polarisation in radiative B decays

- Measuring the photon polarisation
  - The time-dependent CP-asymmetry in $B_{(s)} \to f^{CP}\gamma$: $B_s^0 \to \phi\gamma$, $B^0 \to K_S^0\pi^0\gamma$
  - **Angular correlations among the three-boday decay products of the excited kaons in $\mathbf{B \to K_{res}(P_1P_2P_3)\gamma}$: $B \to K_1(K\pi\pi)\gamma$, $B \to \phi K\gamma$**
  - Transverse asymmetry in $B^0 \to K^*(892)^0 l^+ l^-$
  - Direct measurement of the photon polarisation in baryons decays: $\Lambda_b \to \Lambda^{(*)}\gamma$, $\Xi_b \to \Xi^{(*)}\gamma$
- This talk shows measuring the photon polarisation in $B \to K\pi\pi\gamma$ which has been extensively studied theoretically by M. Gronau, E. Kou *et al*

Photon polarisation in $B \to K_{\text{res}}\gamma$

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

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

  where $c_{L(R)}^{(i)}$ are the weak radiative amplitues $c_{L(R)}^{(i)} \equiv A(\bar{B}(B) \to K_{\text{res}}^{(i)}\gamma_{L(R)})$
- The photon polarisation parameter in $B \to K_{\text{res}}\gamma$ is common to all K_{res}-states

$$\lambda_\gamma^{(i)} = \lambda_\gamma \equiv \frac{|C_{7R}|^2 - |C_{7L}|^2}{|C_{7R}|^2 + |C_{7L}|^2}$$

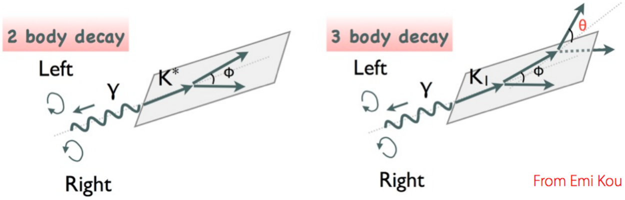
  where $C_{7L(R)}$ are Wilson coefficients
  - $C_{7R}/C_{7L} \simeq m_s/m_b$ in SM, i.e. $+1$ for $\bar{b}$ and -1 for b
  - Much larger C_{7R}/C_{7L} ratios permitted in LR[1] and MSSM[2] extensions of the SM

[1] left-right symmetric model

[2] the unconstrained minimal supersymmetric standard model

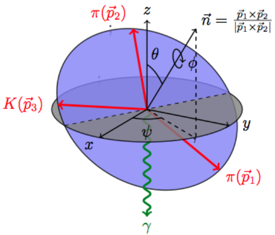
Photon polarisation in $B \to K_{\text{res}}(K\pi\pi)\gamma$

- Three-body decay of K_{res} needed to build a P-odd triple product, $\vec{p}_{\gamma} \cdot (\vec{p}_{\pi} \times \vec{p}_{K})$, which changes sign for left- and right-handed photons.



- The decay amplitude is required to have a non trivial phase due to final state interactions in order to preserve T.
- The strong phase originates from the interference of at least two amplitudes leading to a common three-body final states.

Angular distributions in $B \to K_{\text{res}}(K\pi\pi)\gamma$



- K_{res}-resonance strong decay amplitude can be described by the helicity amplitude $\mathcal{J}_\mu$

$$A^{(i)}_{L(R)}(s, s_{13}, s_{23}, \cos\theta) = \epsilon^{\mu}_{K,L(R)}\mathcal{J}_\mu$$

- Experimentally, we measure the sum of the left- and right-handed current contribution:

$$\Gamma(B \to K_{\text{res}}\gamma) = \Gamma(B \to K_{\text{res}}\gamma_L) + \Gamma(B \to K_{\text{res}}\gamma_R)$$

- Isolated single 1^+ resonance:

$$\frac{d\Gamma(B \to K_{\text{res}}(1^+; P_1P_2P_3)\gamma)}{ds\,ds_{13}\,ds_{23}\,d\cos\theta} \propto \frac{1}{4}|\vec{\mathcal{J}}|^2(1+\cos^2\theta) + \lambda_\gamma \frac{1}{2}\cos\theta\, Im[\vec{n}\cdot(\vec{\mathcal{J}} \times \vec{\mathcal{J}}^*)]$$

- 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.

Angular distributions in $B \to K_{\text{res}}(K\pi\pi)\gamma$

- Considering the interference between different J^P K_{res}-resonances:

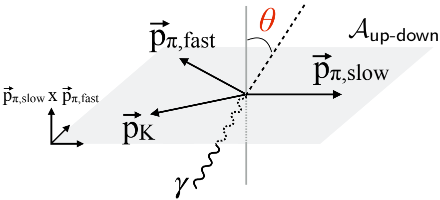
$$\frac{d\Gamma(\sum B \to K_{\text{res}}(P_1 P_2 P_3)\gamma)}{ds ds_{13} ds_{23} d\cos\theta} \propto \sum_{j=even} a_j(s_{13}, s_{23}) \cos^j\theta + \lambda_\gamma \sum_{j=odd} a_j(s_{13}, s_{23}) \cos^j\theta$$

  where functions $a_j(s_{13}, s_{23})$ depend on the resonances present in the $P_1 P_2 P_3$ system and their interferences.
- λ_γ **goes with odd powers of** $\cos\theta$
- $\mathcal{J}$ changes sign under the exchange of s_{13} and s_{23}.

Up-down asymmetry

- Up-down asymmetry: the asymmetry between the measured number of signal events with the photons emitted above and below the $P_1P_2P_3$ decay plane in the K_{res} reference plane

$$\color{red}{\cos\theta} = \text{sgn}(s_{13} - s_{23})\cos\theta$$



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

$$= \frac{3}{4}\lambda_\gamma \frac{\int ds ds_{13} ds_{23} Im[\vec{n}\cdot(\vec{\mathcal{J}}\times\vec{\mathcal{J}}^*)]}{\int ds ds_{13} ds_{23} |\vec{\mathcal{J}}|^2}$$

- The up-down asymmetry is proportional to the photon polarisation λ_γ
- In case of $K_1(1400)$[3]: $\mathcal{A}_{\text{up-down}} \sim 0.3\lambda_\gamma$ for neutral $K_1(1400)$ decays (SM: -0.3 with λ_γ = -1) and $\sim 0.1\lambda_\gamma$ in charged ones.

[3] PRD 66 (2002) 054008

The LHCb experiment

Tracking:

$\Delta p/p \sim 0.4\%$ at 5GeV

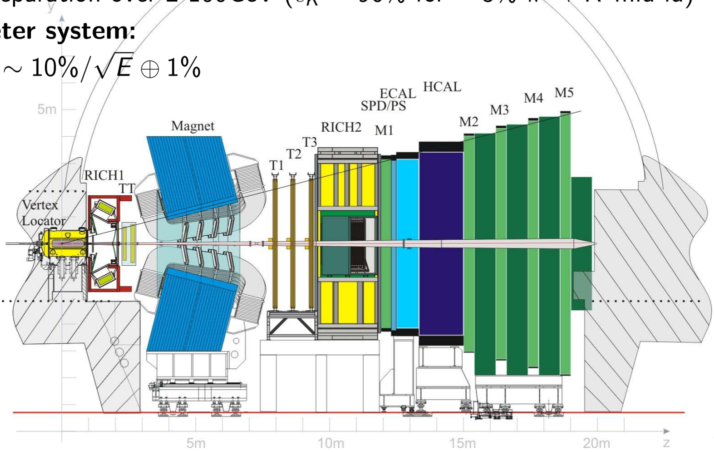
$\sigma_{\text{IP}} \sim 20\mu m$ for high-p_T tracks and $\sigma_\tau \sim 45 fs$

Particle identification:

π/K separation over 2-100GeV ($\epsilon_K \sim 90\%$ for $\sim 5\%$ $\pi \to K$ mid-id)

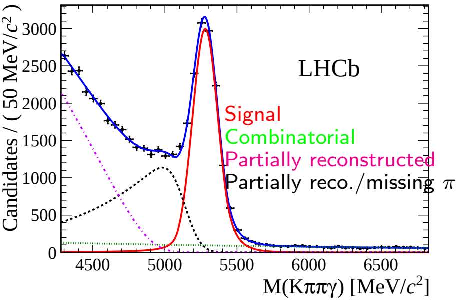
Calorimeter system:

$\sigma_E/E \sim 10\%/\sqrt{E} \oplus 1\%$

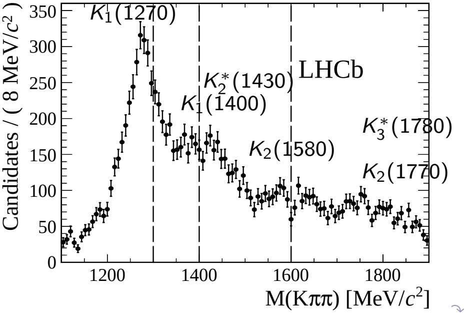


$B^\pm \to K^\pm \pi^\mp \pi^\pm \gamma$ at LHCb

- Data collected in 2011 and 2012, corresponding to an integrated luminosity of 3 fb^{-1}
- A total signal yield of 13876±153 events from the fit of the mass distribution of the selected $B^\pm \to K^\pm \pi^\mp \pi^\pm \gamma$ candidates
- The $K\pi\pi$ mass region of [1.1,1.9] GeV/c^2 is studied
  - [1100, 1300] MeV/c^2: the leading contribution from $K_1(1270)^+$ resonance
  - [1300, 1400] MeV/c^2: the $K_1(1270)^+$ and $K_1(1400)^+$ interfere
  - [1400, 1600] MeV/c^2: the $K_1(1400)^+$ and $K_2^*(1430)^+$ dominate
  - [1600, 1900] MeV/c^2: higher spin resonances contributions are expected



[PRL 112, 161801 (2014)]

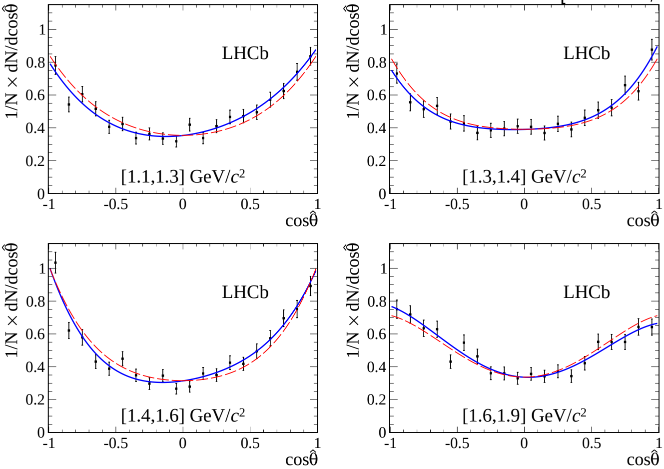


Angular distribution[4]

$f(\cos\hat{\theta}; c_0 = 0.5, c_1, c_2, c_3, c_4) = \sum_{i=0}^{4} c_i L_i(\cos\hat{\theta})$ (c_i: Legendre coefficients)

No odd components, i.e. $\mathcal{A}_{\mathrm{ud}} = 0$

[PRL 112, 161801 (2014)]



[4] The background-subtracted $\cos\hat{\theta}$ ($\cos\hat{\theta} \equiv \text{charge(B)} \cos\theta$) distribution is corrected for the selection acceptance and normalized to the inverse of the bin width.

Up-down asymmetry

$$\mathcal{A}_{ud} = \frac{c_1 - c_3/4}{2c_0}$$

$\times 10^{-2}$

	[1.1,1.3]	[1.3,1.4]	[1.4,1.6]	[1.6,1.9]
c_1	6.3 ± 1.7	5.4 ± 2.0	4.3 ± 1.9	-4.6 ± 1.8
c_2	31.6 ± 2.2	27.0 ± 2.6	43.1 ± 2.3	28.0 ± 2.3
c_3	-2.1 ± 2.6	2.0 ± 3.1	-5.2 ± 2.8	-0.6 ± 2.7
c_4	3.0 ± 3.0	6.8 ± 3.6	8.1 ± 3.1	-6.2 ± 3.2
$\mathcal{A}_{ud}$	6.9 ± 1.7	4.9 ± 2.0	5.6 ± 1.8	-4.5 ± 1.9

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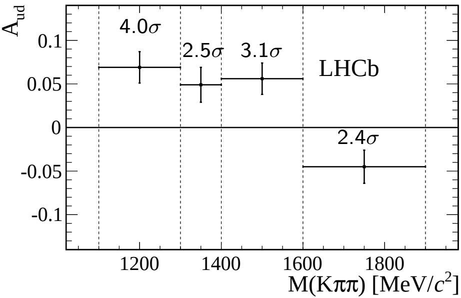
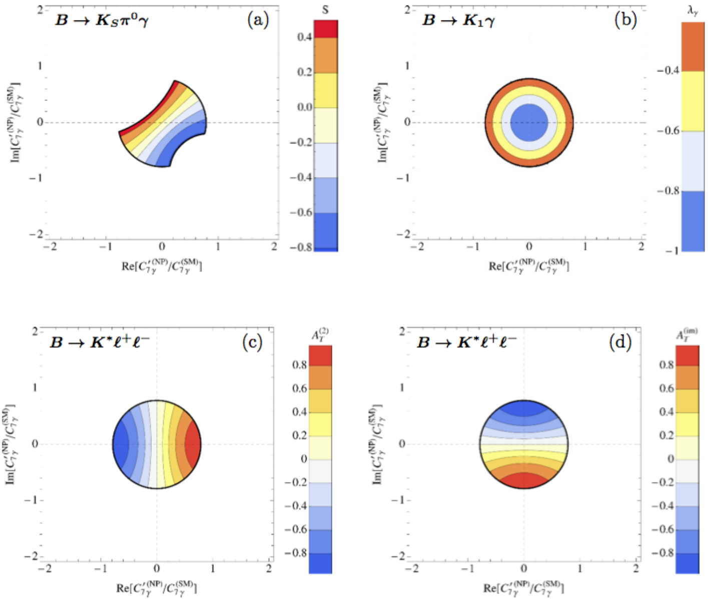


- A combined significance with respect to the non-polarisation scenario is extracted with $\mathcal{A}_{ud}$ different from zero at 5.2σ
- **First observation of photon polarisation in $b \to s\gamma$ transition!**
- Detailed knowledge of the strong interactions of the K_{res} decay required to extract the photon polarisation
- The coefficients of the angular fit as well as correlation matrices obtained for each of the four $K\pi\pi$ mass regions prove to be a useful input for theorists

Summary and future

- Summary
  - A study of $B^{\pm} \to K^{\pm}\pi^{\mp}\pi^{\pm}\gamma$ decay performed on 3 fb^{-1} data sample
  - Photon polarisation has been observed for the first time in $b \to s\gamma$ transitions
- Future
  - Perform a full amplitude analysis of the $B^{\pm} \to K^{\pm}\pi^{\mp}\pi^{\pm}\gamma$ decay
    - A precise information on the helicity amplitude $\mathcal{J}$ is needed
    - Several possible K_{res}-resonances are existed
    - The pattern of decays of K_{res} resonance is also complex
    - The full amplitude analysis is dedicated to isolate single K_{res}-resonance
  - The measurement of the photon polarisation at LHCb can also be done (is doing) with
    - Proper time distribution of $B_s^0 \to \phi\gamma$
    - Transverse asymmetry in $B^0 \to K^* e^+ e^-$
    - Angular distribution in $B^+ \to \phi K^+ \gamma$
    - Radiative b-baryon decays: $\Lambda_b \to \Lambda^{(*)}\gamma$, $\Xi_b \to \Xi^{(*)}\gamma$
  - More results are coming soon!

Constraints on $C_{7\gamma}^{(\prime)}$ in the NP scenario



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

- The radiative differential decay rate:

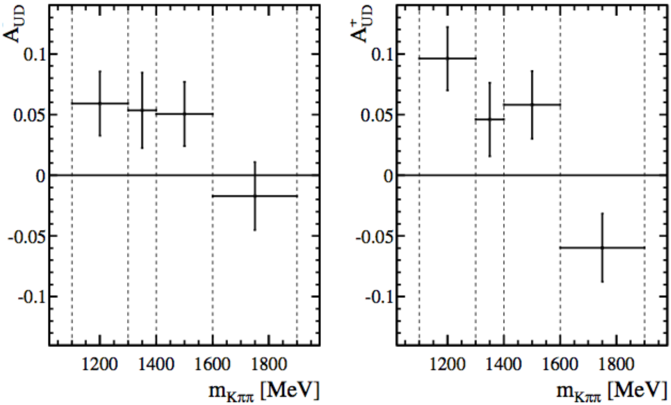
$$d\Gamma(B \to K\pi\pi\gamma) = |\sum_i \frac{c_R^{(i)} A_R^{(i)}}{s - M_i^2 - iM_i\Gamma_i}|^2 + |\sum_i \frac{c_L^{(i)} A_L^{(i)}}{s - M_i^2 - iM_i\Gamma_i}|^2$$
$$\propto (|\mathcal{A}_R|^2 + |\mathcal{A}_L|^2) + \lambda_\gamma(|\mathcal{A}_R|^2 - |\mathcal{A}_L|^2)$$

- The photon polarisation in $B \to K\pi\pi\gamma$ is defined by

$$P_\gamma = \frac{\Gamma(B \to K\pi\pi\gamma_R) - \Gamma(\bar{B} \to K\pi\pi\gamma_L)}{\Gamma(B \to K\pi\pi\gamma_R) + \Gamma(\bar{B} \to K\pi\pi\gamma_L)}$$
$$= \frac{\int dPS(|\mathcal{A}_R|^2 - |\mathcal{A}_L|^2) + \lambda_\gamma \int dPS(|\mathcal{A}_R|^2 + |\mathcal{A}_L|^2)}{\int dPS(|\mathcal{A}_R|^2 + |\mathcal{A}_L|^2) + \lambda_\gamma \int dPS(|\mathcal{A}_R|^2 - |\mathcal{A}_L|^2)}$$

- Only with single resonance, $P_\gamma = \lambda_\gamma$

Up-down asymmetry with a counting method



The counting method gives compatible results

An alternative definition of the photon angle

$\vec{n}' = \vec{p}_{\pi^-} \times \vec{p}_{\pi^+}$ instead of $\vec{n} = \vec{p}_{\pi,\mathrm{slow}} \times \vec{p}_{\pi,\mathrm{fast}}$

	[1.1,1.3]	[1.3,1.4]	[1.4,1.6]	[1.6,1.9]
c'_1	-0.9 ± 1.7	7.4 ± 2.0	5.3 ± 1.9	-3.4 ± 1.8
c'_2	31.6 ± 2.2	27.4 ± 2.6	43.6 ± 2.3	27.8 ± 2.3
c'_3	0.8 ± 2.6	0.8 ± 3.1	-4.4 ± 2.8	2.3 ± 2.7
c'_4	3.4 ± 3.0	7.0 ± 3.6	8.0 ± 3.1	-6.6 ± 3.2
$\mathcal{A}'_{\mathrm{ud}}$	-1.1 ± 1.7	7.2 ± 2.0	6.4 ± 1.8	-3.9 ± 1.9