Prospects on radiative decays: photon polarisation

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Outline

- Photon polarisation in the SM and extensions
- Measurement through $B_s \to \phi\gamma$
- Measurement through $B \to K_1\gamma$
- Conclusions

Photon polarisation in the SM and beyond

- In the SM, photons from $b \to s \gamma_L$ are mainly left-handed.
  - Small correction from $m_s/m_b \sim 0.02$.

$$\mathcal{H}_{eff} = -\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \left(\sum_{i=1}^{6} C_i(\mu)\mathcal{O}_i(\mu) + C_{7\gamma}(\mu)\mathcal{O}_{7\gamma}(\mu) + C_{8g}(\mu)\mathcal{O}_{8g}(\mu) \right)$$

- This left-handedness has never been confirmed up to a high precision.
- Several models predict an enhancement of the right-handed component.
  - Left-right symmetric models **[Babu et al. PLB 333, (1994)]**
  - SUSY-GUT models **[Gabbiani et al. NPB 477 (1997)]**
  - Models with new particles changing the chirality in the loop
- Right-handed contribution still allowed from inclusive $BR(B \to X_s \gamma)$

The polarisation measurement

- We do not have polarising filters in the detector. Need to build observables related to the handedness.

$$O = \frac{\Gamma(b \to s\gamma_R)}{\Gamma(b \to s\gamma_L)}$$

- Several methods proposed:
  - Transverse asymmetry in $B_d \to K^* l^+ l^-$ ($A_T^{(2)}$, $A_T^{(im)}$)
    [Kruger, Matias PRD71 ; Becirevic, Sneider NPB854]
  - Time-dependent CP asymmetry in $B_d \to K_s \pi^0 \gamma$, $B_s \to K^+ K^- \gamma$
    [Atwood et al.PRL79]
  - Angular analysis and Dalitz plot in $B \to K_1 \gamma$
    [Gronau et al. PRL88 ; Kou, Le Yaounac, Tayduganov PRD83]
  - Measurements using B-baryons
    [Gremm et al. PLB355 (1995); Mannel et al. PLB255 (1991); Legger et al. PLB649 (2007); Oliver et al.]

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See Nicola's slides and previous session

This talk

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

Photon polarisation through time-dependent CP asymmetry

- Time-dependent decay rate of a generic B meson to a CP eigenstate is

$$\Gamma_{B\to\phi^{CP}\gamma}(t) \propto |A|^2 e^{-\Gamma t}\left(\cosh\frac{\Delta\Gamma t}{2} - \mathcal{A}^{\Delta}\sinh\frac{\Delta\Gamma t}{2} + \mathcal{C}\cos\Delta m t - \mathcal{S}\sin\Delta m t\right)$$

$$\Gamma_{\bar{B}\to\phi^{CP}\gamma}(t) \propto |A|^2 e^{-\Gamma t}\left(\cosh\frac{\Delta\Gamma t}{2} - \mathcal{A}^{\Delta}\sinh\frac{\Delta\Gamma t}{2} - \mathcal{C}\cos\Delta m t + \mathcal{S}\sin\Delta m t\right)$$

$$\mathcal{S} = \sin 2\psi \sin\phi$$

$$\mathcal{A}^{\Delta} = \sin 2\psi \cos\phi$$

$\mathcal{C} \simeq 0$ In the SM, as this is the direct CP asymmetry

$$\tan\psi \equiv \frac{\mathcal{A}(\bar{B}\to\phi^{CP}\gamma_R)}{\mathcal{A}(\bar{B}\to\phi^{CP}\gamma_L)}$$

The observable that quantifies the amount of photons “wrongly” polarised

In the decay rate, the photon polarisation appears through two parameters, S and A^{Δ}

The B_s case

- Theory and the LHCb measurements yield that $\phi_s \simeq 0 \Rightarrow \mathcal{S} = 0$

  [Phys. Lett. B 713 (2012) 378-386]
  [Phys. Rev. Lett. 108 (2012) 101803]
  [Phys. Lett. B 707 (2012) 497–505]

- Simplification of decay rate, still dependent on photon polarisation.

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

$$\Gamma_{B_s \to \phi\gamma}(t) = \Gamma_{\bar{B}_s \to \phi\gamma}(t)$$

$$\mathcal{A}^{\Delta}_{B_s} \simeq \sin 2\psi$$

- Measure directly the decay rate of B_s, no flavour tagging is required.
- Need as input Γ_s and $\Delta\Gamma_s$

LHCb studies [F. Soomro LHCb-THESIS-2011-035]

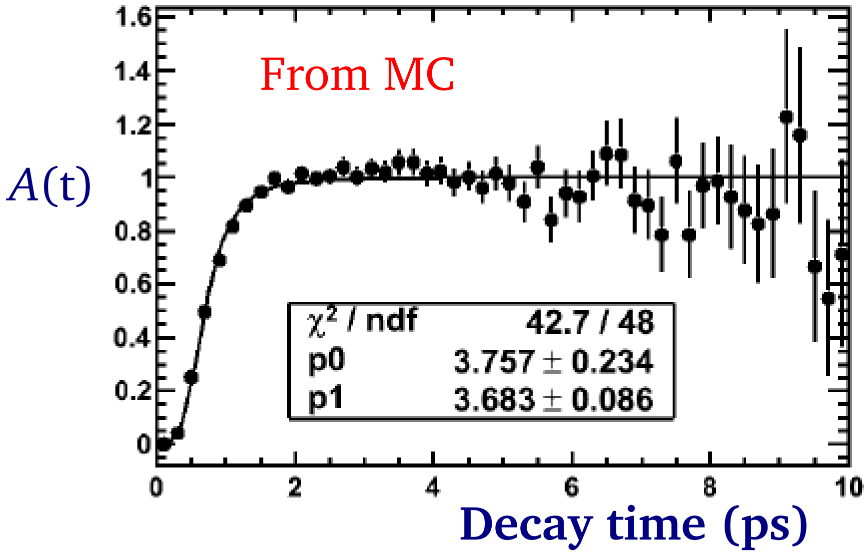
- Knowledge of Γ_s (better than 1%) and $\Delta\Gamma_s$
- Knowledge of the **acceptance function at 2-3%** level to get an uncertainty on σ_A=0.2.
- Decay time resolution and its bias.

- The decay-time resolution does not affect the uncertainty on A^{Δ}
  - But bias could introduce a syst. effect
- The acceptance function is the trickiest issue.
  - Arises from the fact that the event selection performed affects the lifetime distribution of the candidates.

Acceptance function extraction

- Typical turn-on curve for the acceptance function of events at LHCb.
  - Modelled as:

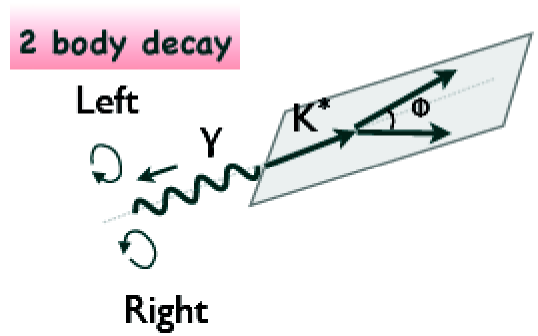
$$A(t) = \frac{a \cdot t^n}{1 + a \cdot t^n} \cdot (1 + \beta \cdot t)$$

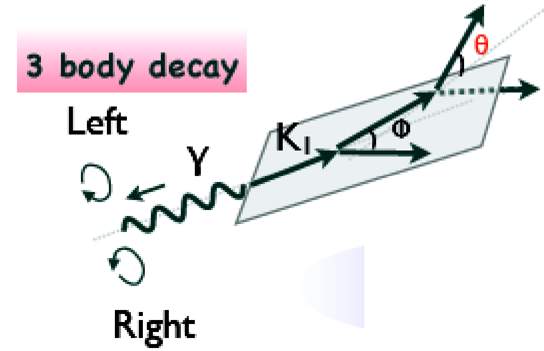


- Several attemps to extract it:
  - From $B_s \to \phi\gamma$ MC → Would prefer data driven extraction, but work in progress.
  - From $B_d \to K^*\gamma$ data → Cannot use it as there are differences between the two channels (e.g. vertex).
  - From $B_s \to J/\psi\phi$ data
  - More sophisticated methods are under study.

Photon polarisation in $B \to K_1(K\pi\pi)\gamma$

The importance of three-body decay





Two-body decays are symmetric along the helicity axis. No left-right distinction.

Three-body decays can make an angle wrt the helicity axis.

- The average value of the triple product $\vec{p}_\gamma \cdot (\vec{p}_1 \times \vec{p}_2)$ has one sign for left-handed photons and the opposite for right-handed.
- Two methods proposed:
  - (GGPR method) Up-down asymmetry: count the number of events with γ above/below the K_1 plane [Gronau et al. Hep-ph/0107254]
  - (DDLR method) Use angular distribution + Dalitz plot of the 3-body decay (used at ALEPH for τ polarisation) [Davier et al. PLB306 1993]

GGPR method: Up-down asymmetry

- The amplitude of the process is

$$|A(\bar{B} \to \bar{K}_1\gamma, \bar{K}_1 \to \bar{K}\pi\pi)|^2 = |c_L|^2|\mathcal{M}_L|^2 + |c_R|^2|\mathcal{M}_R|^2$$

where weak and strong decay amplitudes are separated. Then,the photon polarisation is defined as

$$\lambda_\gamma = \frac{|c_R|^2 - |c_L|^2}{|c_R|^2 + |c_L|^2} = \frac{|\mathcal{C}'_{7\gamma}|^2 - |\mathcal{C}_{7\gamma}|^2}{|\mathcal{C}'_{7\gamma}|^2 + |\mathcal{C}_{7\gamma}|^2}$$

$$\mathcal{A} = \frac{\int_0^{\pi/2} \frac{d\Gamma}{d\cos\theta} d\cos\theta - \int_{\pi/2}^{\pi} \frac{d\Gamma}{d\cos\theta} d\cos\theta}{\int_0^{\pi} \frac{d\Gamma}{d\cos\theta} d\cos\theta} = \boxed{\frac{\left\langle Im\left(\hat{n} \cdot (\vec{J} \times \vec{J}^*)\right)\right\rangle}{\left\langle|\vec{J}^2|\right\rangle}}\boxed{\lambda_\gamma}$$

Extracted from theory. Decay amplitude of $K_1 \to K\pi\pi$

Photon polarisation

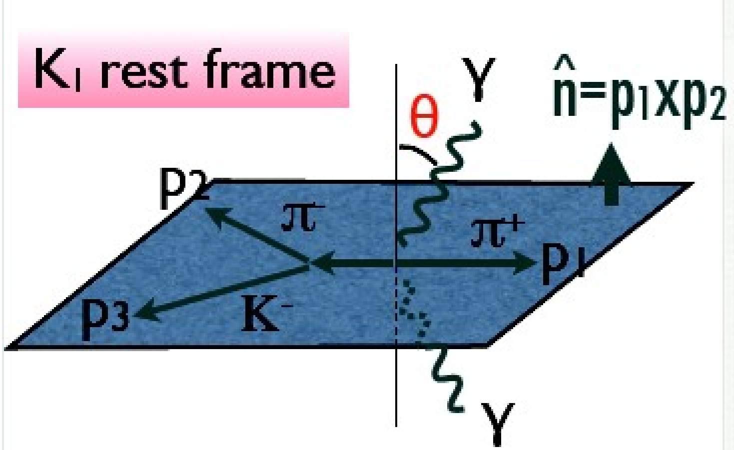
DDLR method: improved measurement using Dalitz plot

[Kou, Le Yaouanc, Tayduganov PRD83 2011]

- The decay distribution for $B \to K_1(K\pi\pi)\gamma$ is given by:

$$\frac{d\Gamma}{ds_{13}ds_{23}d\cos\theta} \propto \frac{1}{4}|\vec{J}^2|(1+\cos^2\theta) + \frac{\lambda_\gamma}{2} Im\left(\hat{n}\cdot(\vec{J}\times\vec{J}^*)\right)\cos\theta$$

The polarisation information is not only on the angular distribution, but also on the Dalitz distribution.

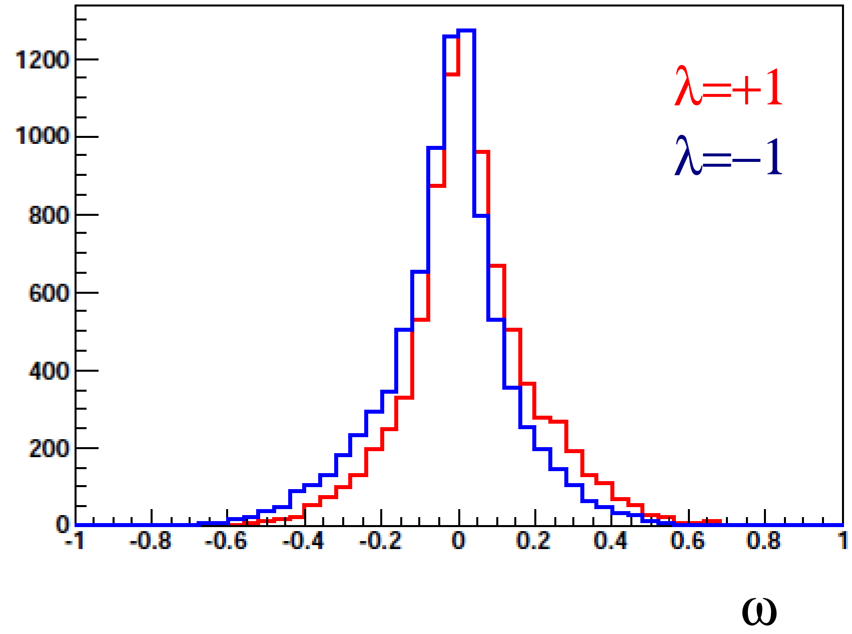


Simplify the analysis using $\omega(s_{13}, s_{23}, \cos\theta) \equiv \frac{2Im[\hat{n}\cdot(\vec{J}\times\vec{J}^*)]\cos\theta}{|\vec{J}|^2(1+\cos^2\theta)}$

DDLR method: improved measurement using Dalitz plot

- Measure the polarisation as:
  - Compute the ω variable per event, knowing the J function.
  - Make a ω distribution
  - Polarisation is $\lambda = \langle\omega\rangle / \langle\omega^2\rangle$

Simulated distribution of λ

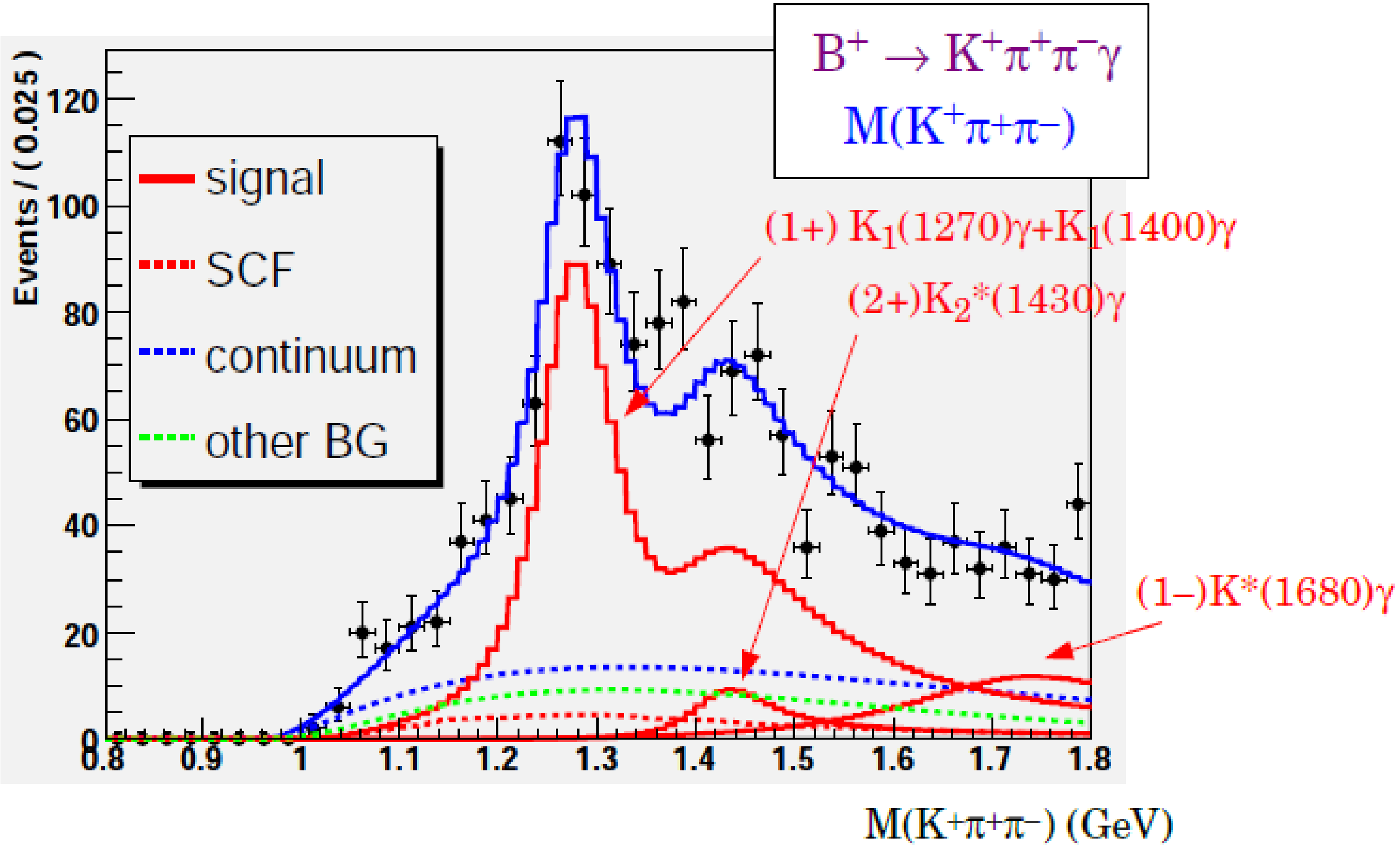


How to know the J function?

- Need to know the hadronic information of the $K_1 \to K\pi\pi$ decay.
- 1) Model dependent way:
  - Extracted from theory. Assume that decay comes from quasi-two body decay $K_1 \to K^*\pi$ & $K_1 \to \rho K$. J function is written in terms of:
    - 4 form factors (S,D partial wave amplitudes)
    - 2 couplings ($g_{K^*K\pi}$, $g_{\rho\pi\pi}$)
    - 1 relative phase between the two decays.
  - Large hadronic uncertainties.
  - Expect ~30% uncertainty in the measurement.
- 2) Model independent way:
  - Extracted from data e.g. $B \to K_1\ J/\psi$. Need to address the systematic effect induced by the $J/\psi \leftrightarrow \gamma$ exchange.

Belle observation

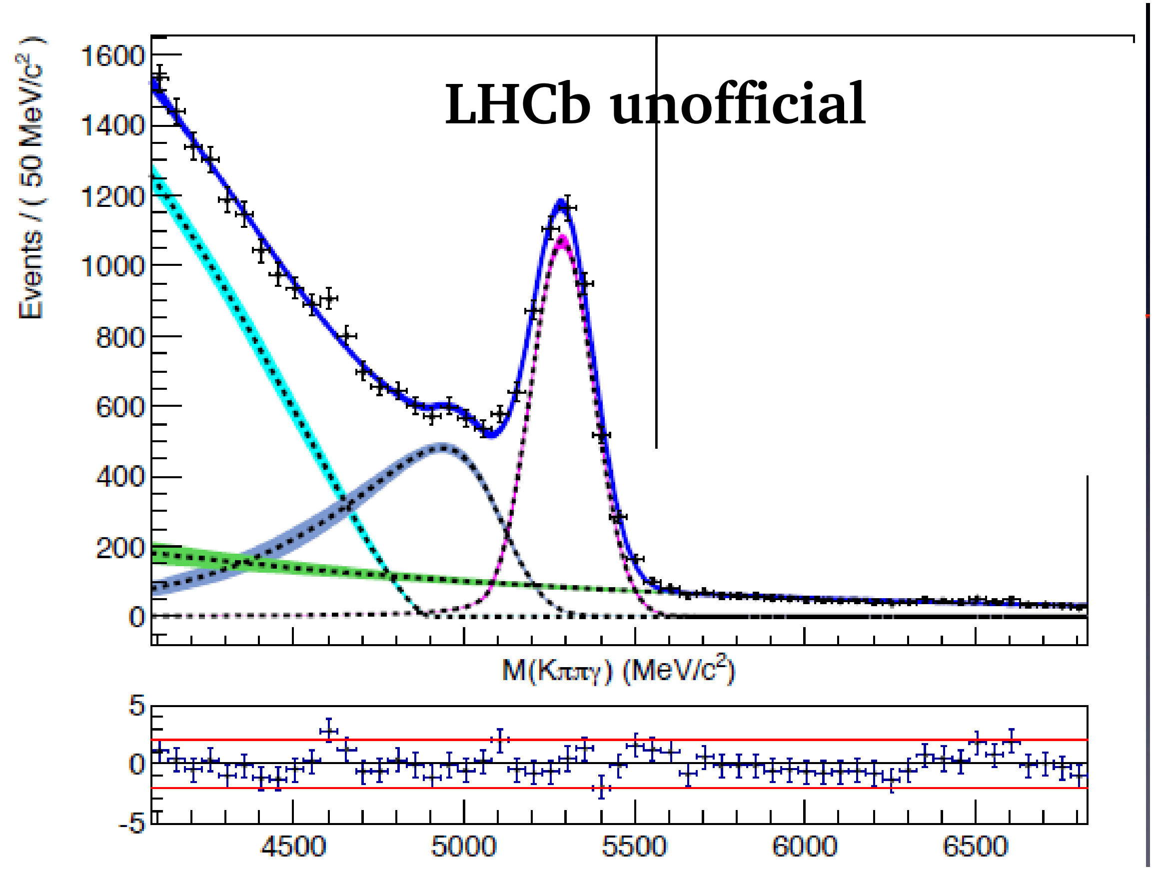
- Observation of $B \to K_1(1270)\gamma$ with (7.3σ) BR $(4.3 \pm 1.3) \times 10^{-5}$
- $B \to K_1(1400)\gamma$ not yet been observed.



B→Kππγ events at LHCb (very preliminary)

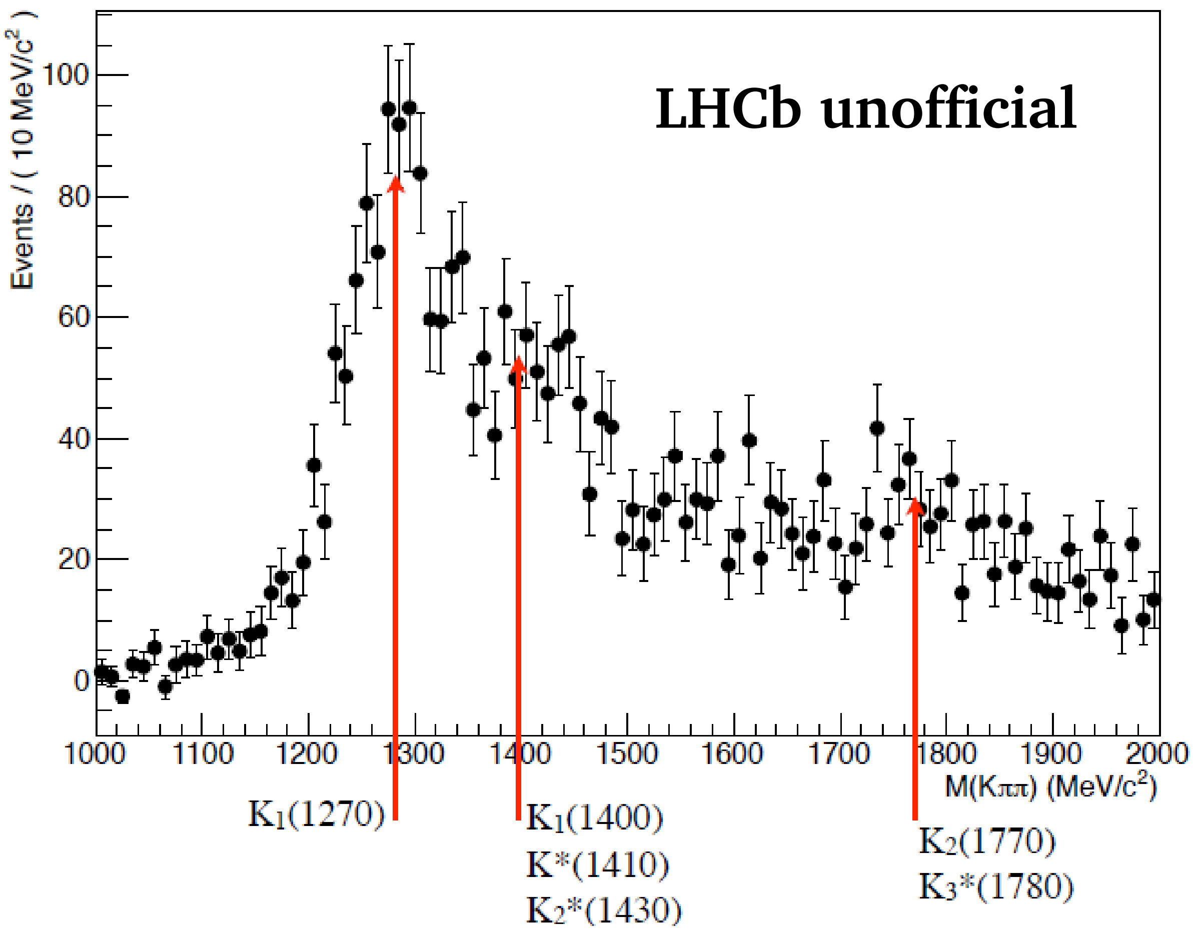
- Using 1.5 fb^{-1} of 2012 data, we are able to reconstruct 5100±100 Kππγ events.

Signal
Comb. Bkg
Partially reco'd bkg n-body (B→hh(h)π^0X)
Partially reco'd, 1 missing π (B→K*ργ)



Other bkg	Contamination
$B^0 \to K^{*0}(K^+\pi^-)\gamma$	~ 2.4×10^{-3}
$B^+ \to K^{*+}(K^+\pi^0)\pi^+\pi^-$	~ 4×10^{-4}
$B^+ \to D^0(K^+\pi^-\pi^0)\pi^+$	< 7.6×10^{-2}
$B^+ \to D^{*0}(D^0(K^+\pi^-)\gamma)\pi^+$	< 9×10^{-4}

Kππ mass spectrum (very preliminary)



Need to determine precisely the resonant composition of the Kππ mass spectrum (Still $2fb^{-1}$ to be analysed).

Conclusions

- Two of the methods proposed to study the photon polarisation (with on-shell photons) are being studied by LHCb.
- Both present difficulties:
  - $B_s \to \phi\gamma$ is well understood (bkg, signal shape), but need to know the proper-time acceptance function with high precision.
  - $B \to K_1(K\pi\pi)\gamma$ clear signal is observed. Need to understand the $K\pi\pi$ mass spectrum composition.
- Expected sensitivities are ~0.3 in the photon polarisation with 2011+2012 data.
- Still work to do, but the work so far seem promising.

Back-up

Right-handed component still allowed

- The amplitude including a right-handed component is:

$$\mathcal{M}(b \to s\gamma) \simeq -\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \left[\underbrace{(C_{7\gamma}^{\rm SM} + C_{7\gamma}^{\rm NP}) \langle \mathcal{O}_{7\gamma} \rangle}_{\propto \mathcal{M}_L} + \underbrace{C_{7\gamma}'^{\rm NP} \langle \mathcal{O}'_{7\gamma} \rangle}_{\propto \mathcal{M}_R} \right]$$

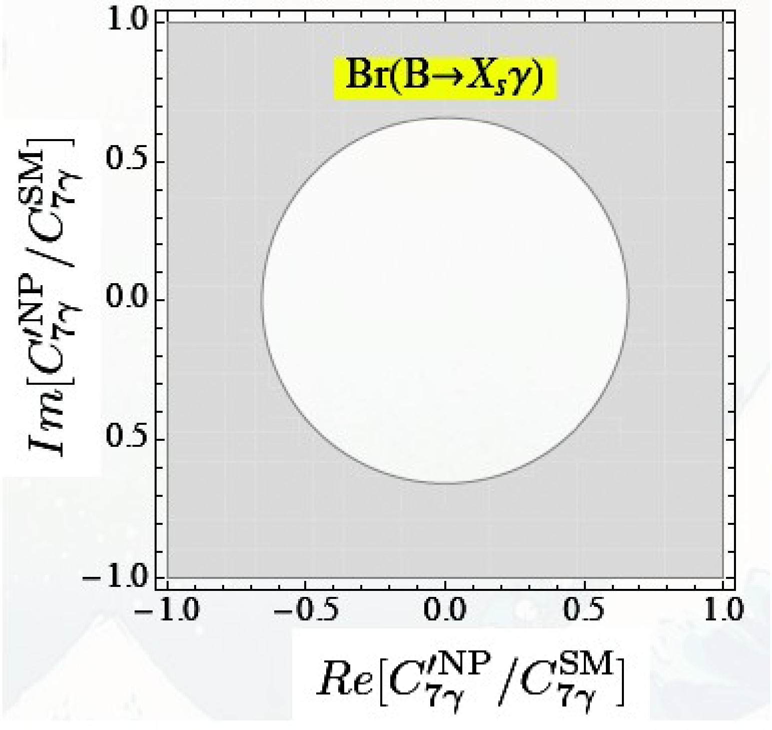
$$Br(B \to X_S\gamma) \propto |C_{7\gamma}^{\rm SM} + C_{7\gamma}^{\rm NP}|^2 + |C_{7\gamma}'^{\rm NP}|^2$$

= (3.55±0.24±0.09) x 10^{-4}

The polarisation is

$$\frac{\mathcal{M}_R}{\mathcal{M}_L} \simeq \frac{C_{7\gamma}'^{\rm NP}}{C_{7\gamma}^{\rm SM} + C_{7\gamma}^{\rm NP}}$$

Assuming $C_{7\gamma}$(NP)=0



$B_s \to \phi\gamma$ mass shape

- Good knowledge of the signal shape and background contamination.