Exclusive $B \to K^{**}\gamma$ decays

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- Model predictions for absolute rates
- $B \to K\pi\pi\gamma$ correlations as a probe of photon helicity

$b \to s\gamma$ in the Standard Model

- In the Standard Model, $b \to s\gamma$ decays are mediated by the electromagnetic penguin operator

$$\mathcal{H}_{\text{eff}} = \frac{G_F}{\sqrt{2}} V_{ts} V_{tb}^* C_7 \mathcal{O}_7 \qquad \left(\mathcal{O}_7 = \frac{e m_b}{16\pi^2} \bar{s} \sigma_{\mu\nu} \frac{1}{2}(1+\gamma_5) b F^{\mu\nu} \right)$$

	Experiment	Theory (SM)
$Br(B \to X_s\gamma)$	$(3.22 \pm 0.40) \times 10^{-4}$	$(3.29 \pm 0.33) \times 10^{-4}$

- Couples mostly to left-handed photons because of the $(V-A)$ $W^{\pm}$ couplings to quarks in the Standard Model (right-handed for $\bar{b} \to \bar{s}\gamma$)
- The most general case can include both left- and right-handed couplings

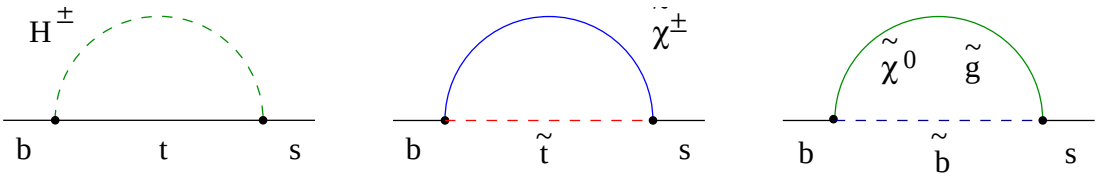
$$\mathcal{H}_{\text{eff}} = \frac{G_F}{\sqrt{2}} V_{ts} V_{tb}^* \left(C_{7L} \mathcal{O}_{7L} + C_{7R} \mathcal{O}_{7R} \right)$$

- While the rate is only sensitive to $|C_{7R}|^2 + |C_{7L}|^2$, the photon polarization can probe the individual Wilson coefficients

$$P_\gamma = \frac{|C_{7R}|^2 - |C_{7L}|^2}{|C_{7R}|^2 + |C_{7L}|^2}$$

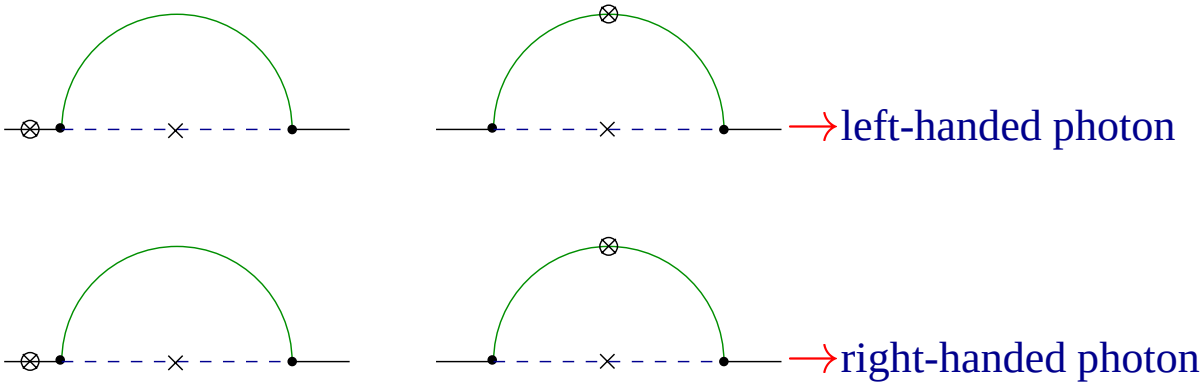
Beyond the Standard Model

- MSSM: new additional particles can run in the loop



(charged Higgs) (chargino, stop) (gluino, sbottom)

- The chirality flip can happen on the b-quark or on the $\tilde{g}$ line



Borzumati, Greub, Hurth, Wyler (2000)

- Minimal Flavor Violation: the New Physics contributions producing a right-handed photon cancel
- C_{7R} scenario: complete cancellation with $W^{\pm}$ leaving $C_{7L} = 0$ Everett, Kane, Rigolin et al (2001)
- The left-right symmetric model $SU_L(2) \times SU_R(2)$ can also produce right-handed photons

Cho, Misiak (1997)

Exclusive $B \to X_s\gamma$ decays

The exclusive modes are dominated by the lowest lying vector meson K^*

$$\begin{aligned} \mathcal{B}(B^+ \to K^{*+}\gamma) &= (3.83 \pm 0.62 \pm 0.22) \times 10^{-5} \\ \mathcal{B}(B^0 \to K^{*0}\gamma) &= (4.23 \pm 0.40 \pm 0.22) \times 10^{-5} \end{aligned}$$

Higher excitations have been also seen

$$Br(B \to K_2^*(1430)\gamma) = \begin{cases} (1.50^{+0.58+0.11}_{-0.53-0.13}) \times 10^{-5} & \text{(CLEO)} \\ (1.66^{+0.59}_{-0.53} \pm 0.13) \times 10^{-5} & \text{(BELLE)} \end{cases}$$

The absolute values of the rates depend on the value of a hadronic form factor - can be computed in models

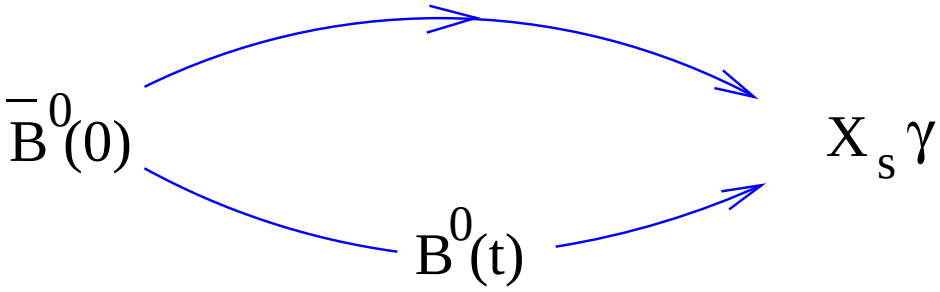
	J^P	(M, Γ)	$\mathcal{B}/\mathcal{B}(B \to X_s\gamma)$
$K_1(1270)$	1^+	(1273, 90)	4.3 ± 1.6
$K_1(1400)$	1^+	(1402, 174)	2.1 ± 0.9
$K_1^*(1410)$	1^-	(1414, 232)	4.1 ± 0.6
$K_2^*(1430)$	2^+	(1430, 100)	6.2 ± 2.9

The numerical estimates are from the quark model calculation of Olsson, Veseli - Phys. Lett. B367, 309, 1996

Measuring the photon polarization in $b \to s\gamma$

- Time-dependent CP asymmetry in $B^0(t) \to K^*/\rho\gamma$

  Atwood, Gronau, Soni (1995)

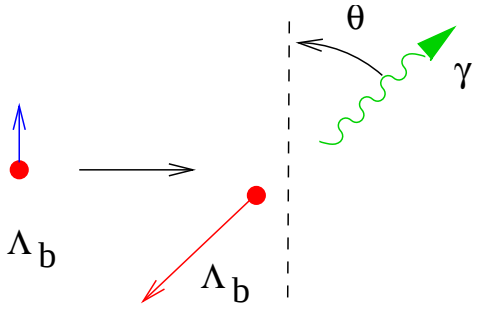


$$A_{CP}(t) = \frac{2\mathrm{Re}(C_{7L}C_{7R}^*)}{|C_{7R}|^2 + |C_{7L}|^2} \sin 2\beta \sin(\Delta m t)$$

Problems: small Br $\simeq 10^{-6}$, need for tagging and time-dependent measurements

- Angular distributions in $\Lambda_b \to \Lambda\gamma$ decays

  Mannel, Recksiegel(1999) Kagan, Hiller (2001)



$$\simeq 1 + \langle P_{\Lambda_b} \rangle \frac{|C_{7L}|^2 - |C_{7R}|^2}{|C_{7L}|^2 + |C_{7R}|^2} \cos\theta$$

Problems: feasible only at e^+e^- machines (Giga-Z), small Λ_b polarization?

- Angular correlations in $B \to (K^* \to K\pi)e^+e^-$

  Kim^2, Lü, Morozumi (2000), Grossman, Pirjol (2000)

Photon polarization from $B \to (K^{**} \to K\pi\pi)\gamma$ angular correlations

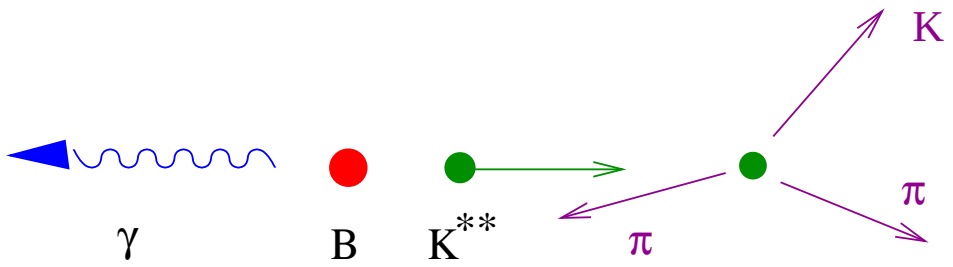
- In the decay $B \to K^*\gamma$, the photon helicity is transferred to the hadron K^*. Is it possible to measure it through the strong decays $K^* \to |f\rangle$?

This requires $|A(K^*_R \to f)| \neq |A(K^*_L \to f)|$

- In two body decays $K^* \to K\pi$ parity invariance of the strong interactions rules out a right/left asymmetry.

This is possible in 3-body decays of K^{**} resonances

Gronau, Grossman, D.P., Ryd (2001)



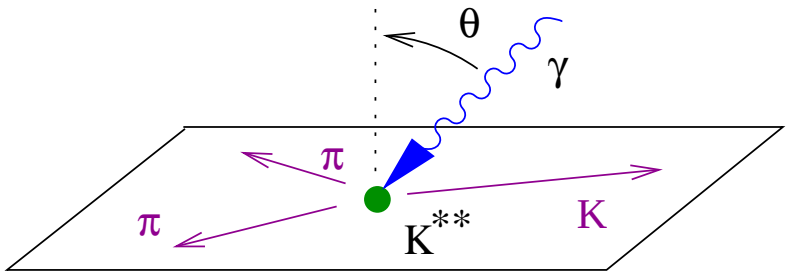
- Such decays have been recently observed at CLEO (2000) and BELLE (2001)

$$Br(B \to K_2^*(1430)\gamma) = \begin{cases} (1.50^{+0.58+0.11}_{-0.53-0.13}) \times 10^{-5} & \text{(CLEO)} \\ (1.66^{+0.59}_{-0.53} \pm 0.13) \times 10^{-5} & \text{(BELLE)} \end{cases}$$

The most general distribution involves the interference of multiple decay channels and partial waves $\rightarrow$ strong phases required for a nonvanishing $T-$odd asymmetry

$$B^+ \rightarrow \left\{ \begin{array}{c} K_1(1400) \\ K_1(1410) \\ K_2^*(1430) \end{array} \right\} \gamma \rightarrow \left\{ \begin{array}{c} K^{*+}\pi^0 \\ K^{*0}\pi^+ \\ \rho^+ K^0 \end{array} \right\} \gamma \rightarrow K^0\pi^+\pi^0\gamma\,.$$

Many of the partial widths and strong phases have been directly measured in a $K\pi\pi$ production experiment (ACCMOR (1981)).



$$\begin{aligned}
\Gamma \simeq \quad & |c_1|^2 \left(1+\cos^2\theta + P_\gamma R_1 \cos\theta\right) && (1^+) \\
+ \quad & |c_2|^2 \left(\cos^2\theta + \cos^2 2\theta + P_\gamma R_2 \cos\theta\cos 2\theta\right) && (2^+) \\
+ \quad & |c_3|^2 \sin^2\theta && (1^-) \\
+ \quad & c_{12}(3\cos^2\theta - 1) + c'_{12} P_\gamma \cos^3\theta && (1^+ - 2^+)
\end{aligned}$$

Gronau, D.P. (2002)

$$R_1 = 0.22 \pm 0.03\,, \quad R_2 = 0.01 - 0.05$$

$\rightarrow$ angular measurements can disentangle the resonances and allow the extraction of the photon polarization.

Conclusions

- The photon polarization in $b \to s\gamma$ contains information about the Wilson coefficients of the penguin operators in the weak Hamiltonian and can offer important clues about New Physics contributions to rare B decays
- New method for extracting the photon polarization through T-odd correlations in $B \to (K_{\rm res} \to K\pi\pi)\gamma$ decays
- Advantages compared with previous methods:
  - Both charged and neutral B's can be used $\to$ larger branching ratios
  - No tagging and time-dependent measurements required
- Assuming dominance by the $K_1(1400)$ resonance, about 80 B decays are required to confirm the SM prediction of a left-handed photon $P_\gamma = -1$ at a 3σ level. Such a measurement is well within the reach of existing B factories!