Photon Polarization with anomalous right-handed top couplings in $B \to K_{res}\gamma$

Based on hep-ph/0309018

At Seoul WorldCup Stadium (Sang-Am)

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Why $B \to K_{res}\gamma$?

- $b \to s\gamma$ is a good testing ground for the Standard Model and probing new physics.
- Photons from $b \to s\gamma$ are predominantly left-handed in the SM up to m_s/m_b.
- K_{res} hadronic three-body decay ($\to K\pi\pi$) can provide a direct measurement of the photon polarization λ_γ through a triple vector product $p_\gamma \cdot (p_1 \mathrm{x} p_2)$.
- Current *B* factories are capable of doing the analysis.

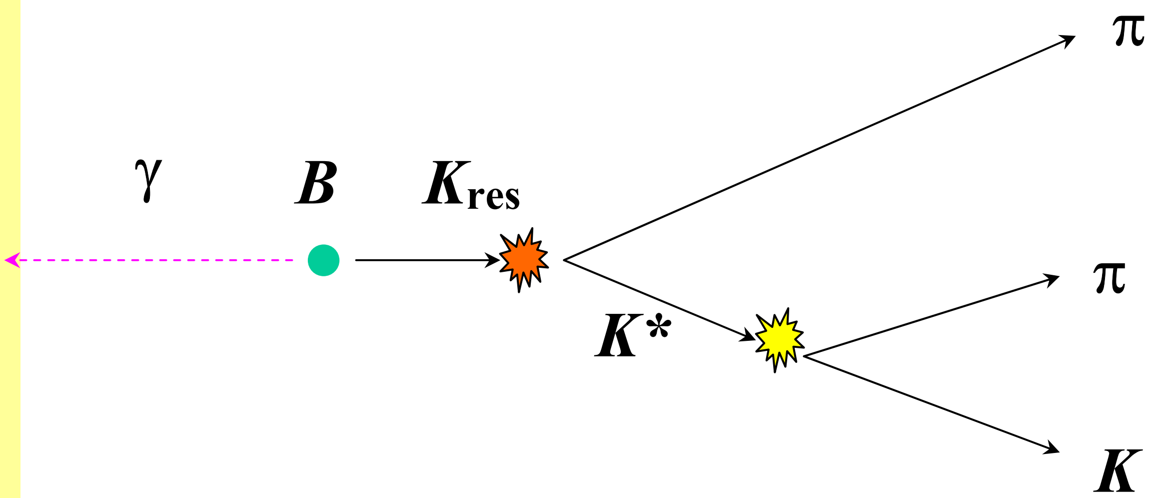
Kaon Resonances

Resonances	J^P	(M_{res},Γ_{res})(MeV)	Decay Mode	Br(%)
$K_1(1270)$	1^+	(1273+–7, 90+–20)	ρK	42+–6
			$K^*\pi$	16+–5
			$K^{*0}(1430)\pi$	28+–4
$K_1(1400)$	1^+	(1402+–7, 174+–13)	$K^*\pi$	94+–6
			ρK	3.0+–3.0
$K^*(1410)$	1^-	(1414+–15, 232+–21)	$K^*\pi$	>40
			ρK	<7
$K^*_2(1430)$	2^+	(1425.6+–1.5, 98.5+–2.7)	$K^*\pi$	24.7+–1.5
		(charged K^*_2)	ρK	8.7+–0.8

Possible Decay Modes of K_{res}

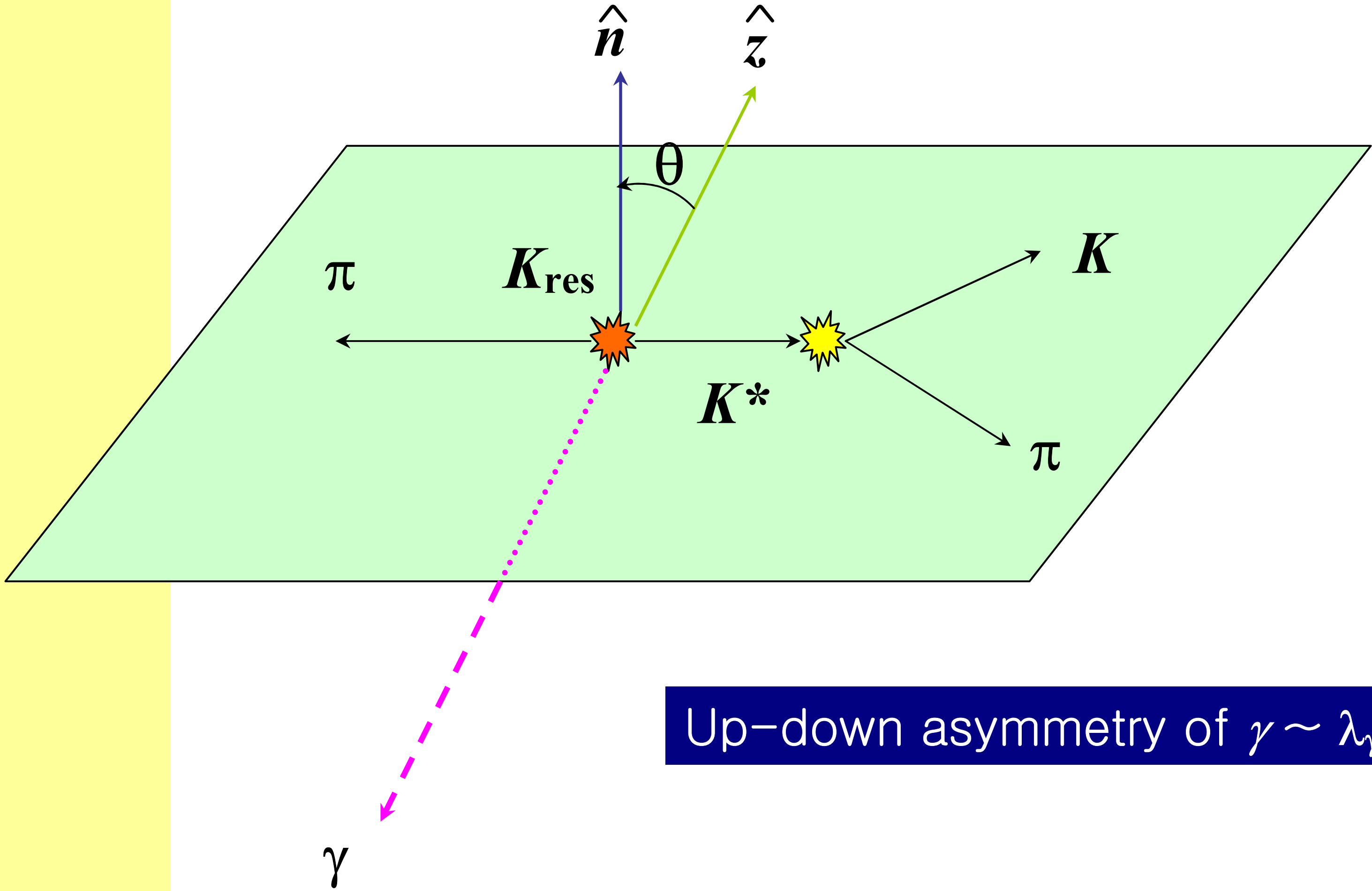
K^{+}_{res} →	$K^{*+}\pi^{0}$, $K^{*0}\pi^{+}$, $\rho^{+}K^{0}$	→ $K^{0}\pi^{+}\pi^{0}$
	$K^{*0}\pi^{+}$, $\rho^{0}K^{+}$	→ $K^{+}\pi^{+}\pi^{-}$
K^{0}_{res} →	$K^{*+}\pi^{-}$, $K^{*0}\pi^{0}$, $\rho^{-}K^{+}$	→ $K^{+}\pi^{-}\pi^{0}$
	$K^{*+}\pi^{-}$, $\rho^{0}K^{0}$	→ $K^{0}\pi^{+}\pi^{-}$

In the Lab frame,



To construct a meaningful triple vector product $p_\gamma \cdot (p_1 \times p_2)$, at least three particles at the final state are needed.

In the K_{res} rest frame,



Up-down asymmetry of $\gamma \sim \lambda_\gamma$

It is known that…

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M. Gronau et al.,
PRL88 (2002) 051802;PRD66 (2002) 054008

Photon up-down asymmetry

- $K_1(1270)$, $K_1(1400)$: Large, $\approx 0.33 \times \lambda_\gamma$
- $K^*(1410)$: No Asymmetry
- $K^*_2(1430)$: Very Small

What to do here?

- Introduce the anomalous right-handed top couplings, $\bar{t}bW$ and $\bar{t}sW$.
- Investigate new effects on λ_γ.
- Current experimental bounds on $B \to X_s\gamma$ are included.
- Ignore possible additional left-handed interactions and new particles.
- Do not consider the underlying models.

Anomalous Couplings

- Effective Lagrangian

$$\mathcal{L} = -\frac{g}{\sqrt{2}} \sum_{q=s,b} V_{tq} \bar{t} \gamma^{\mu} (P_L + \underline{\xi_q P_R}) q W_{\mu}^{+} + \text{h.c.}$$

- Effective Hamiltonian

$$\mathcal{H}_{\rm rad} = -\frac{4G_F}{\sqrt{2}} V_{ts}^{*} V_{tb} \Big[C_{12}(\mu) O_{12}(\mu) + C'_{12}(\mu) O'_{12}(\mu) \Big] \ ,$$

$$O_{12}^{(\prime)} = \frac{e}{16\pi^2} m_b \bar{s} P_{R(L)} \sigma_{\mu\nu} b F^{\mu\nu} \ ,$$

Wilson Coefficients

- In the SM at $\mu=m_W$ ($x_t=m_t^2/m_W^2$)

$$C_{12}(m_W) = F(x_t) = \frac{x_t(7-5x_t-8x_t^2)}{24(x_t-1)^3} - \frac{x_t^2(2-3x_t)}{4(x_t-1)^4}\ln x_t\ ,$$

$$C'_{12}(m_W) = 0\ ,$$

RG evolution to $\mu=m_b$

- After turning on the new couplings

$$C_{12}(m_W) \to F(x_t) + \xi_b\frac{m_t}{m_b}F_R(x_t)\ ,$$

$$C'_{12}(m_W) \to \xi_s\frac{m_t}{m_b}F_R(x_t)\ ,$$

- New loop function

$$F_R(x) = \frac{-20+31x-5x^2}{12(x-1)^2} + \frac{x(2-3x)}{2(x-1)^3}\ln x$$

W.Y. Song and K.Y. Lee, Phys. Rev. D66 (2002) 05
P. Cho and M. Misiak, Phys. Rev. D49 (1994) 5894

γ Polarization Parameter

- **Define** $$\lambda_\gamma^{(i)} = \frac{|A_R^{(i)}|^2 - |A_L^{(i)}|^2}{|A_R^{(i)}|^2 + |A_L^{(i)}|^2}\,, \qquad A_{L(R)}^{(i)} \equiv \mathcal{A}(\bar{B} \to \bar{K}_{\rm res}^{(i)} \gamma_{L(R)})$$

- **Properties**
  - ✓ independent of $K_{\rm res}$ states

$$\lambda_\gamma^{(i)} = \frac{|C'_{12}|^2 - |C_{12}|^2}{|C'_{12}|^2 + |C_{12}|^2} \equiv \lambda_\gamma$$

$$\langle K_{\rm res}^{(i)R} \gamma_R | O'_{12} | \bar{B} \rangle$$
$$= (-1)^{J_i - 1} P_i \langle K_{\rm res}^{(i)L} \gamma_L | O_{12} | \bar{B} \rangle$$
$$|A_R^{(i)}| / |A_L^{(i)}| = |C'_{12}| / |C_{12}|$$

  - ✓ in the SM, $\lambda_\gamma \approx -1$ $(+1$ for $\bar{b} \to \bar{s}\gamma)$

Constraints from $B \to X_s\gamma$

- Experimental bounds

$$\mathrm{Br}(B \to X_s\gamma) = (3.23 \pm 0.41) \times 10^{-4} ,$$

Weighted average over ALEPH, BELLE, and CLEO
G.L. Kane et al., JHEP 01 (2002) 022

$$A_{CP}(B \to X_s\gamma) = \frac{\Gamma(\bar{B} \to X_s\gamma) - \Gamma(B \to X_{\bar{s}}\gamma)}{\Gamma(\bar{B} \to X_s\gamma) + \Gamma(B \to X_{\bar{s}}\gamma)}$$

$$= (-0.079 \pm 0.108 \pm 0.022)(1.0 \pm 0.030)$$

CLEO (2001) result

- Constraints on $\xi_{b,s}$ at 2σ C.L.

$$-0.002 < \mathrm{Re}\xi_b + 22|\xi_b|^2 < 0.0033 ,$$

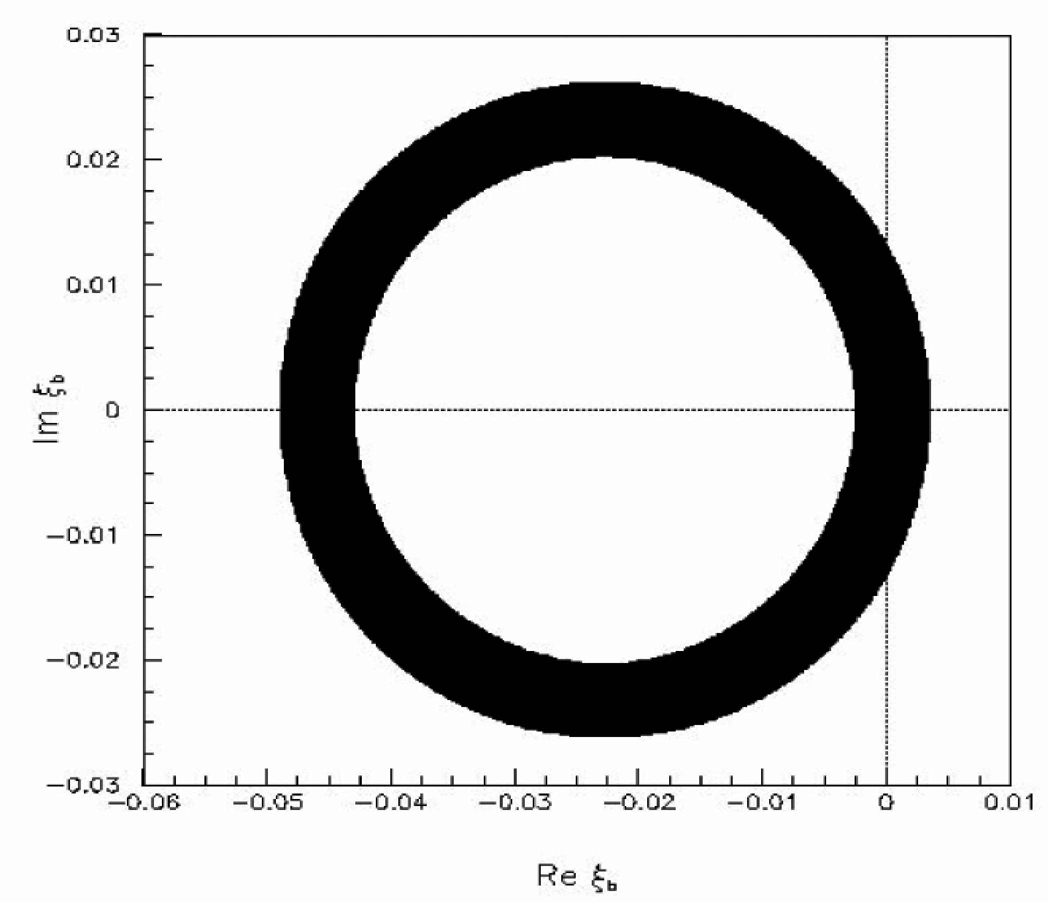
$$-0.299 < \frac{0.27\mathrm{Im}\xi_b}{0.095 + 12.54\mathrm{Re}\xi_b + 414.23|\xi_b|^2} < 0.141 ,$$

$$|\xi_s| < 0.012 .$$

J.-P. Lee and K.Y. Lee, Eur. Phys. J. C 29 (2003) 373

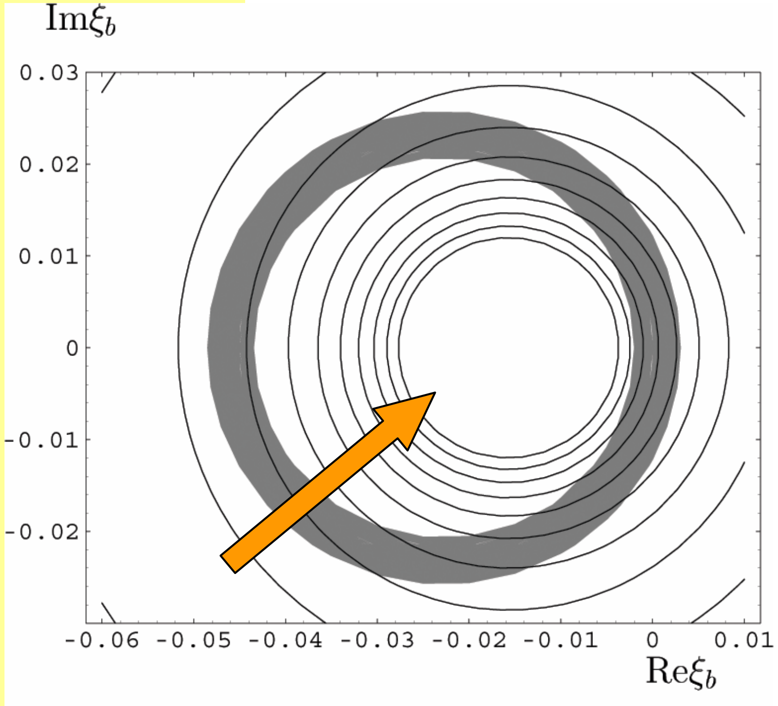
W.Y. Song and K.Y. Lee, Phys. Rev. D66 (2002) 057901

Allowed region of ξ_b

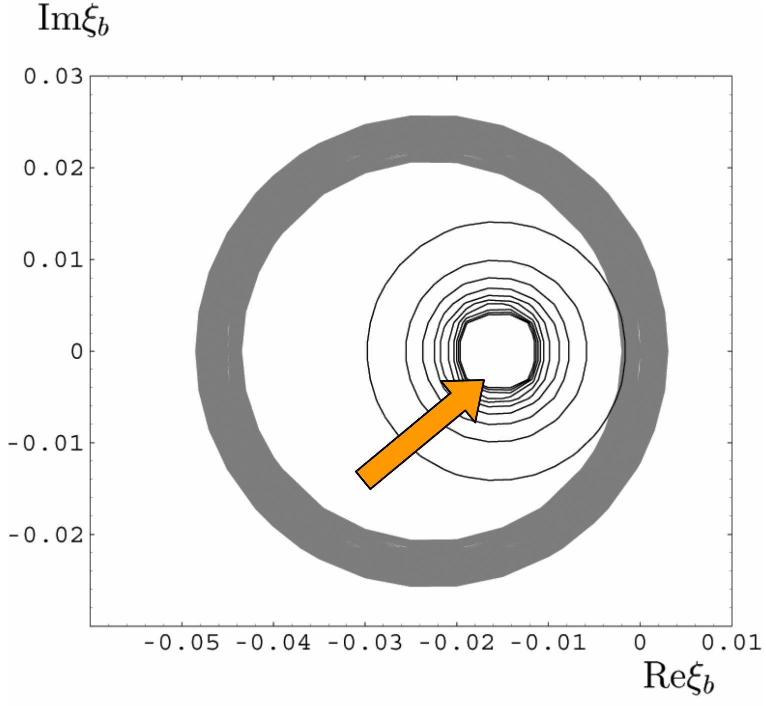


Taken from J.-P. Lee and K.Y. Lee, Eur. Phys. J. C 29 (2003

Contour Plots for λ_γ



(a)



(b)

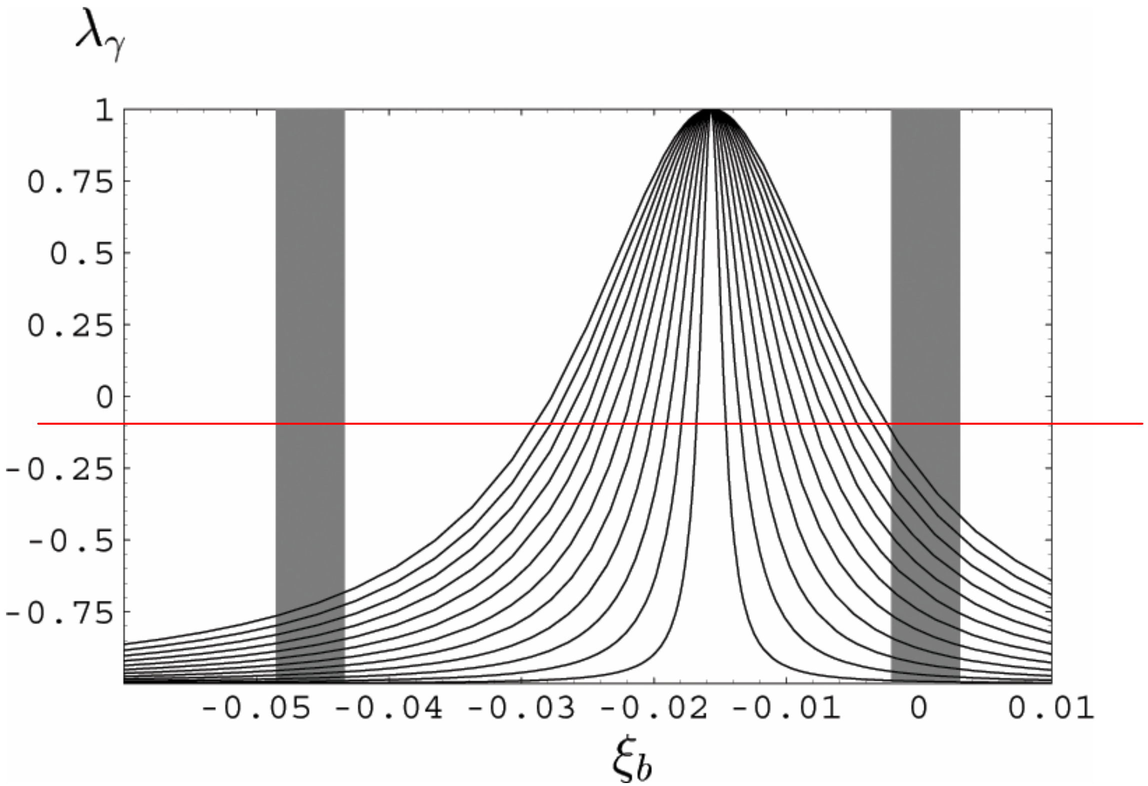
$|\xi_s|=0.012$,

$\lambda_\gamma=-0.9,-0.8,\ldots,0$

$|\xi_s|=0.001$,

$\lambda_\gamma=-0.99,-0.98,\ldots,-0.9$

λ_γ vs ξ_b (Assuming Im$\xi_{b,s}$=0)



ξ_s=0.001,0.002,...,0.012, from bottom to top

Results

- $|\lambda_\gamma|$ can be small for real $\xi_{b,s}$:

$$-1 \leq \lambda_\gamma \lesssim -0.12 \ .$$

- Experimental bounds do not allow the different sign of λ_γ from the SM prediction.
- If the new coupling is flavor-blind (ξ_b=ξ_s), then $\lambda_\gamma \lesssim -0.96$

Comparison with uMSSM

- Chargino, neutralino, and gluino contributions to C_{12} are canceled by the W and Higgs contributions. *G.L. Kane et al., JHEP 01 (2002) 022*
- The main contribution to Br($b\to s\gamma$) is by C'_{12}.

⇒ "C'_{12} –dominated" scenario

- They expect λ_γ **=+1** as an extreme case, quite contrary to the SM prediction.
- If sgn(λ_γ)>0, then the "C'_{12} –dominated" scenario would be more favored.

How many Bs are needed?

- The integrated up-down asymmetry in K_1 is (0.33+–0.05) λ_γ
- In the SM where $\lambda_\gamma \approx -1$, about 80 charged and neutral $B\bar{B}$ decays into $K\pi\pi\gamma$ are needed to measure an asymmetry of –0.33 at 3σ level.
- At least $2 \times 10^7 B\bar{B}$ pairs of both neutral and charged are required.

$$\mathrm{Br}(B \to K_1(1400)\gamma) = 0.7 \times 10^{-5}$$
$$\mathrm{Br}(K_1(1400) \to K^*\pi) = 0.94 \pm 0.06$$

M. Gronau et al., PRL88 (2002) 051802

How many…?

- For smaller value of $|\lambda_\gamma|$, more $B\bar{B}$ pairs are required.
- In case of $\lambda_\gamma = -0.5$, we need 4 times larger number of $B\bar{B}$ pairs (8×10^7).
- This number is already within the reach of current *B* factories!

Summary

- Radiative *B* decays $B \to K_{res}(\to K\pi\pi)\gamma$ are useful for measuring the photon polarization.
- The photon polarization parameter λ_γ encapsulates the emitted photon polarization, which is solely determined by the relevant Wilson coefficients.
- New couplings can reduce $|\lambda_\gamma|$ significantly, compared to the SM prediction $\lambda_\gamma \approx -1$, but would not change the sign.
- Current *B* factories are already within the reach of producing enough *B* mesons.

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