Photon Polarization of b->sgamma: Theory (I)

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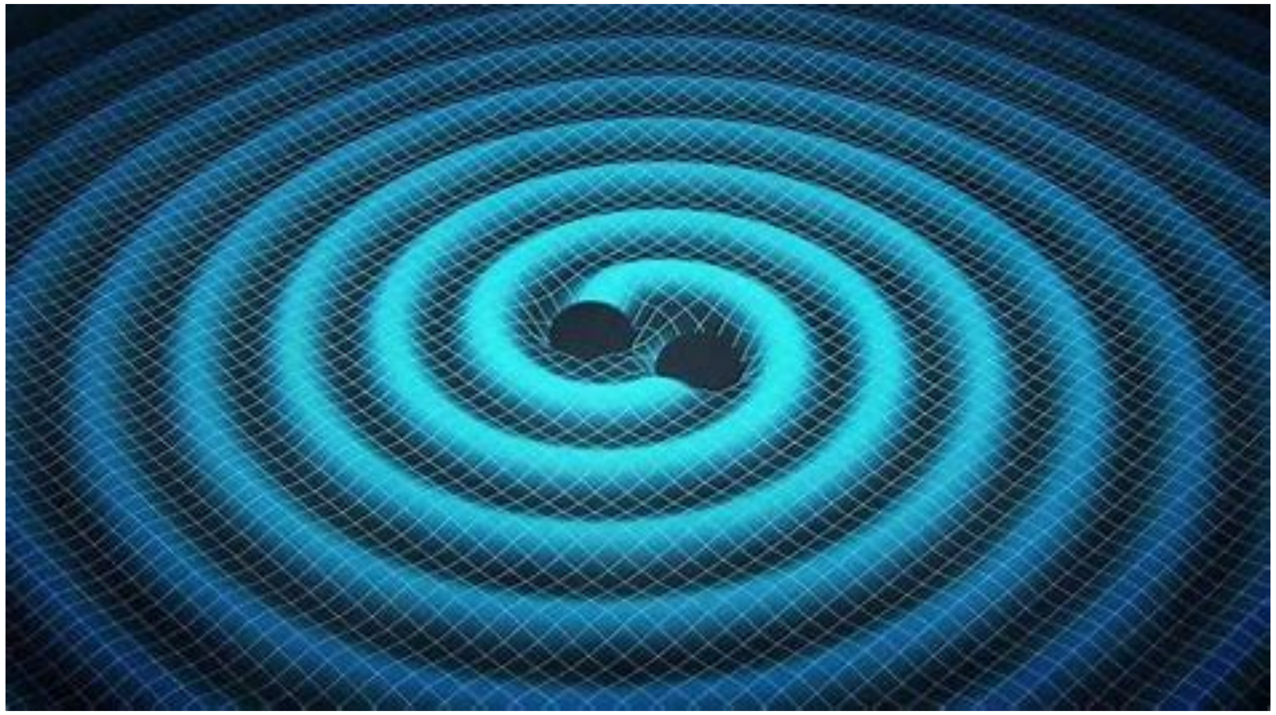
LHCb workshop @ PKU, 2019.12.15

FSY, Kou, C.D.Lu, JHEP (1305.3173)
Akar, Ben-Haim, Hebinger, Kou, **FSY**, JHEP (1802.09433)
W.Wang, **FSY**, Z.X.Zhao, 1909.13083

Big Questions:

Where is new physics?

How to observe it?



Multi-Messenger

To observe a new observable —> photon polarization

Outline

1. Why photon polarization of $b \to s\gamma$

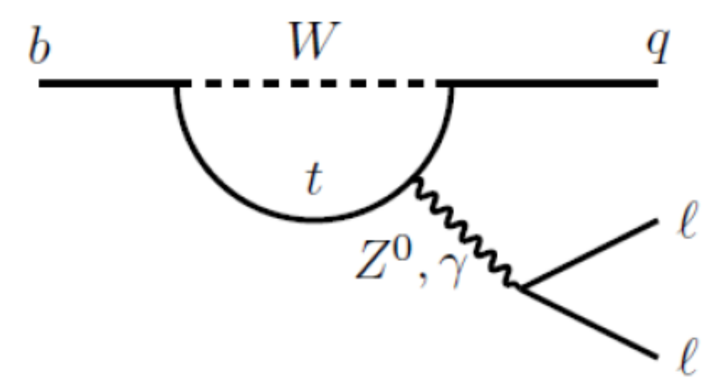
2. Time-dependent CPA in $B^0 \to K_S^0 \pi^+ \pi^- \gamma$

b->s transitions

Flavor-changing-neutral-currents (FCNC)

- Rare decays
- Suppressed in SM
- Sensitive to BSM

semileptonic



BR ~ 10^{-7}

Effective Field Theory

$$H_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha}{4\pi} \left[C_{7\gamma} O_{7\gamma} + C'_{7\gamma} O'_{7\gamma} + \sum_{i=9,10,S,P} \left(C_i O_i + C'_i O'_i \right) \right]$$

$$O'_{7\gamma} = m_b \left(\bar{s} \sigma_{\mu\nu} P_L b \right) F^{\mu\nu}$$

Never observed

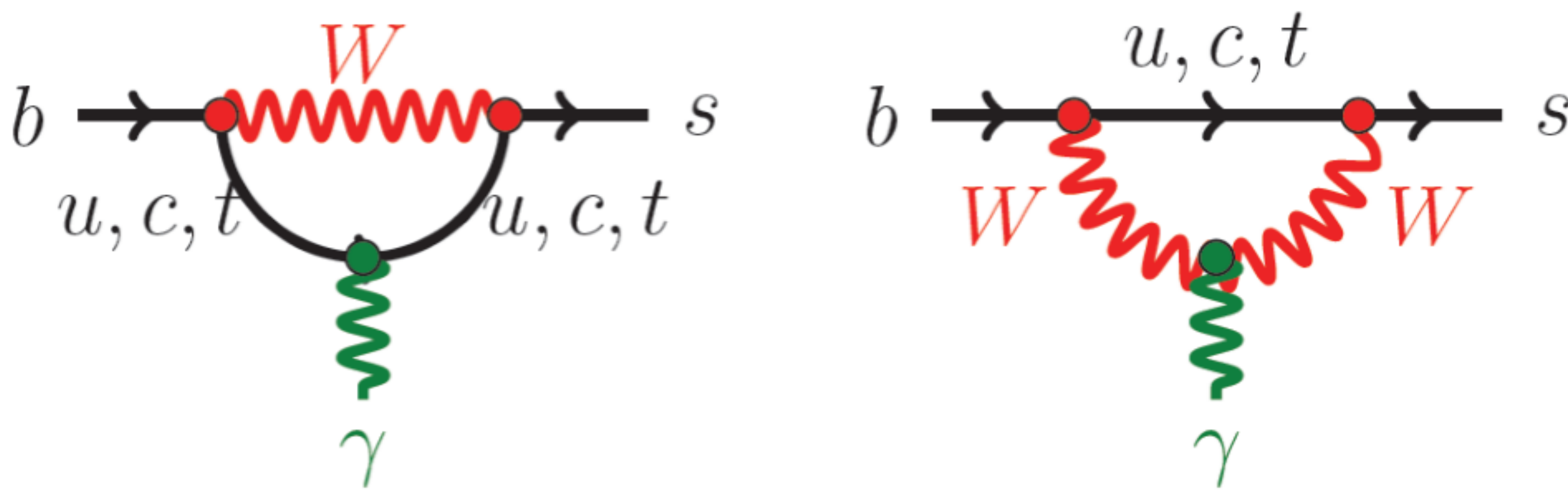
$$O_9 = \left(\bar{s} \gamma_\mu P_L b \right) \left(\bar{\ell} \gamma^\mu \ell \right) \qquad O_S = \left(\bar{s} P_R b \right) \left(\bar{\ell} \ell \right)$$

$$O_{10} = \left(\bar{s} \gamma_\mu P_L b \right) \left(\bar{\ell} \gamma^\mu \gamma_5 \ell \right) \qquad O_P = \left(\bar{s} P_R b \right) \left(\bar{\ell} \gamma_5 \ell \right)$$

Current anomalies in $b \to s\mu^+\mu^-$

1. LFUV RK and RK*
2. $B_s \to \phi \mu^+ \mu^-$
3. P'_5 in $B \to K^* \mu^+ \mu^-$

Photon Polarization in the SM



$$\propto \bar{s}\sigma_{\mu\nu}q^{\nu}\left(m_b\frac{1+\gamma_5}{2}+m_s\frac{1-\gamma_5}{2}\right)b$$

W boson couples only to left-handed quarks in SM

chirality flip on external line

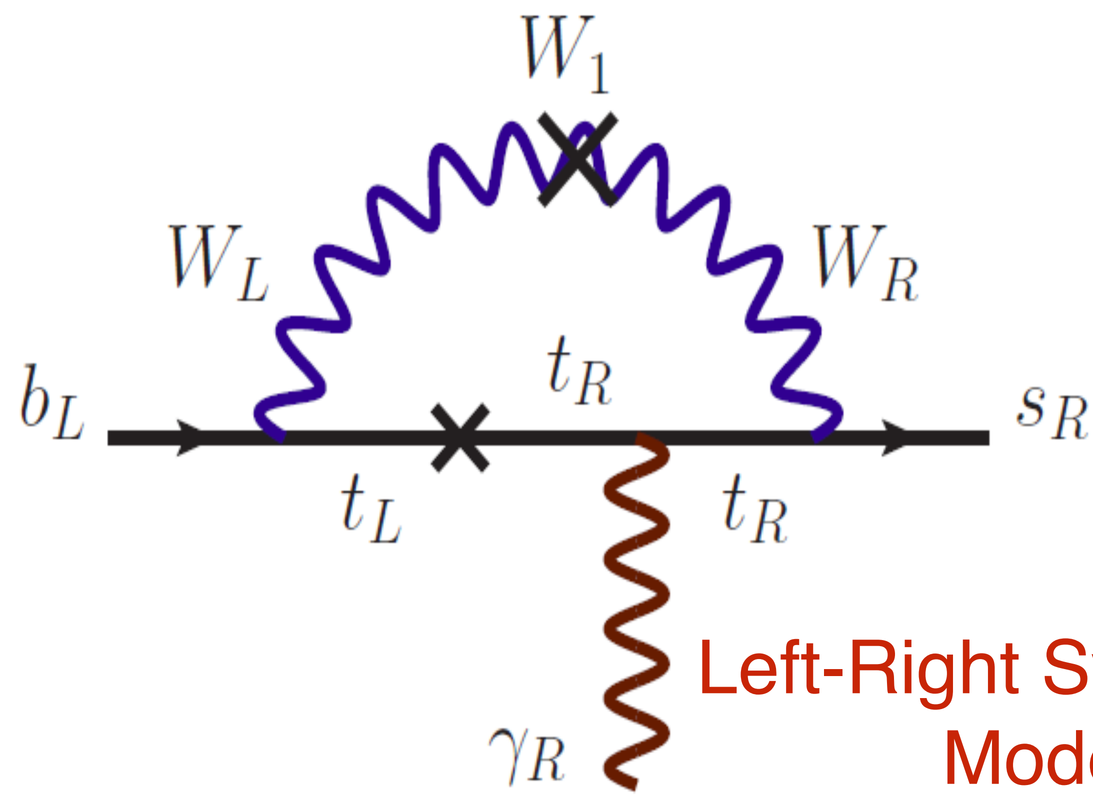
Photon is dominantly **left-handed** in b quark decay in SM

$$\frac{\mathcal{A}(b_L \to s_R\gamma_R)^{LO}_{SM}}{\mathcal{A}(b_R \to s_L\gamma_L)^{LO}_{SM}} = \frac{m_s}{m_b}$$

right-handed in anti-b quark decay

Wrong Polarization may be enhanced in New Physics

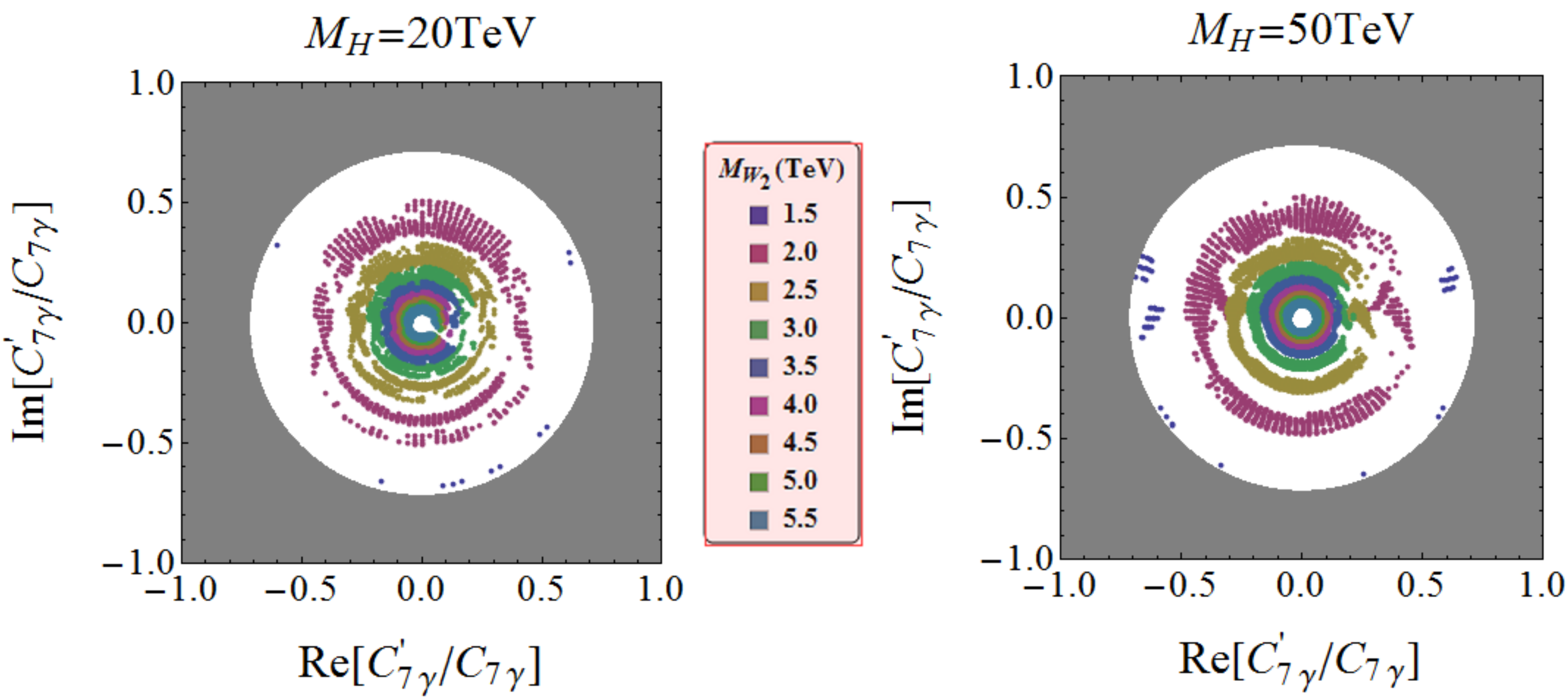
Chiral flip on internal line, resulting in a factor of mt/mb or mNP/mb, instead of ms/mb



Left-Right Symmetric Model

Photon Polarization is useful to search for New Physics models, and needs for more studies.

$Re\left[C'_{7\gamma}/C_{7\gamma}\right]$ v.s. $Im\left[C'_{7\gamma}/C_{7\gamma}\right]$ in the LRSM



FSY, Kou, C.D.Lu, JHEP (1305.3173)

How to Measure Polarization

1. Time-dependent CP asymmetry in

$$B \to f_{CP}\gamma \quad (K_S^0\pi^0\gamma)$$

2. Angular analysis

- Measurement of hadronic state helicity in

$$\bar{B} \to A\gamma \to P_1P_2P_3\gamma$$

- Angular analysis in e+e- low mass region in

$$\bar{B} \to K^* e^+ e^-$$

Time-dependent CP asymmetry in $\bar{B} \to f_{CP}\gamma$ and $\bar{B} \to B \to f_{CP}\gamma$

[Atwood, Gronau, Soni, 1997']

$$A_{CP}(t) \equiv \frac{\Gamma(\overline{B}(t) \to f_{CP}\gamma) - \Gamma(B(t) \to f_{CP}\gamma)}{\Gamma(\overline{B}(t) \to f_{CP}\gamma) + \Gamma(B(t) \to f_{CP}\gamma)} \approx S_{f_{CP}\gamma} \sin(\Delta m t)$$

- **Indirect measurement of photon polarization**

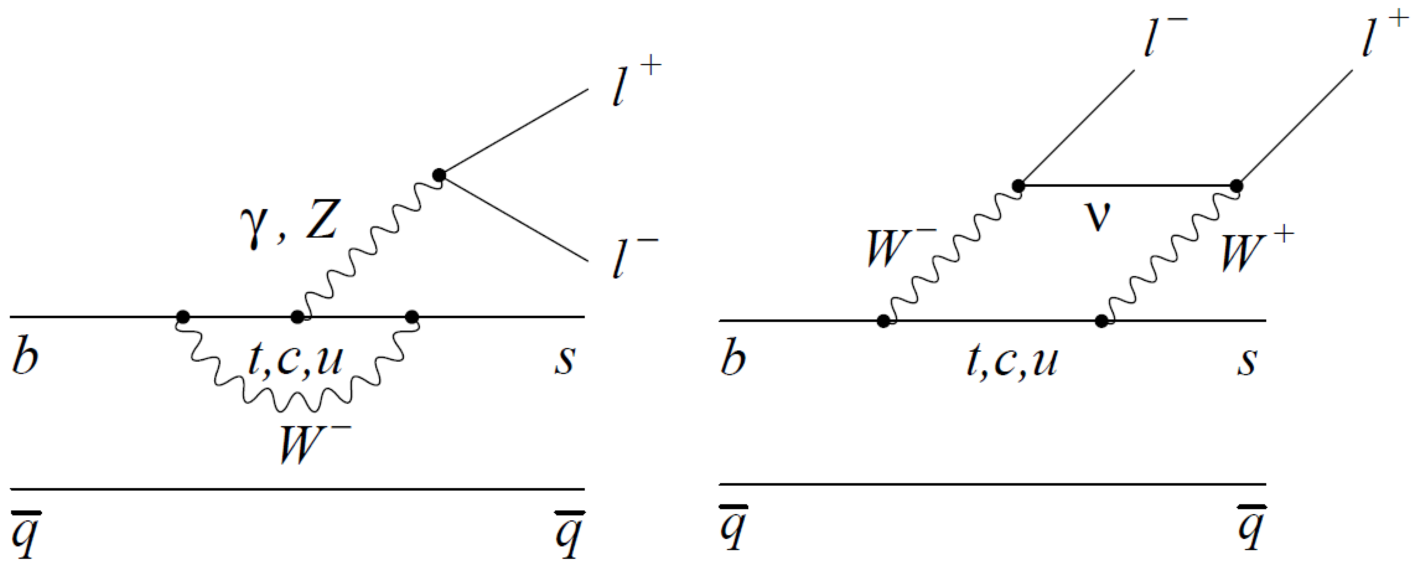
$$S_{f_{CP}\gamma} \equiv \xi \frac{2Im\left[e^{-i\phi_M}\mathcal{M}(\overline{B} \to f_{CP}\gamma_L)\mathcal{M}(\overline{B} \to f_{CP}\gamma_R)\right]}{\left|\mathcal{M}(\overline{B} \to f_{CP}\gamma_L)\right|^2 + \left|\mathcal{M}(\overline{B} \to f_{CP}\gamma_R)\right|^2} \approx \xi \frac{2Im\left[e^{-i\phi_M}C_{7\gamma}C'_{7\gamma}\right]}{|C_{7\gamma}|^2 + |C'_{7\gamma}|^2}$$

$$S^{\mathrm{SM}}_{K_S\pi^0\gamma} = -(2.3 \pm 1.6)\%, \qquad S^{\mathrm{exp}}_{K_S\pi^0\gamma} = -0.16 \pm 0.23$$

[Ball,Jones,Zwicky,PRD2007'] [HFAG, 2013']

- In the future Belle II experiment, the error of S will be significantly reduced down to 2%.

$\bar{B} \to K^* e^+ e^-$

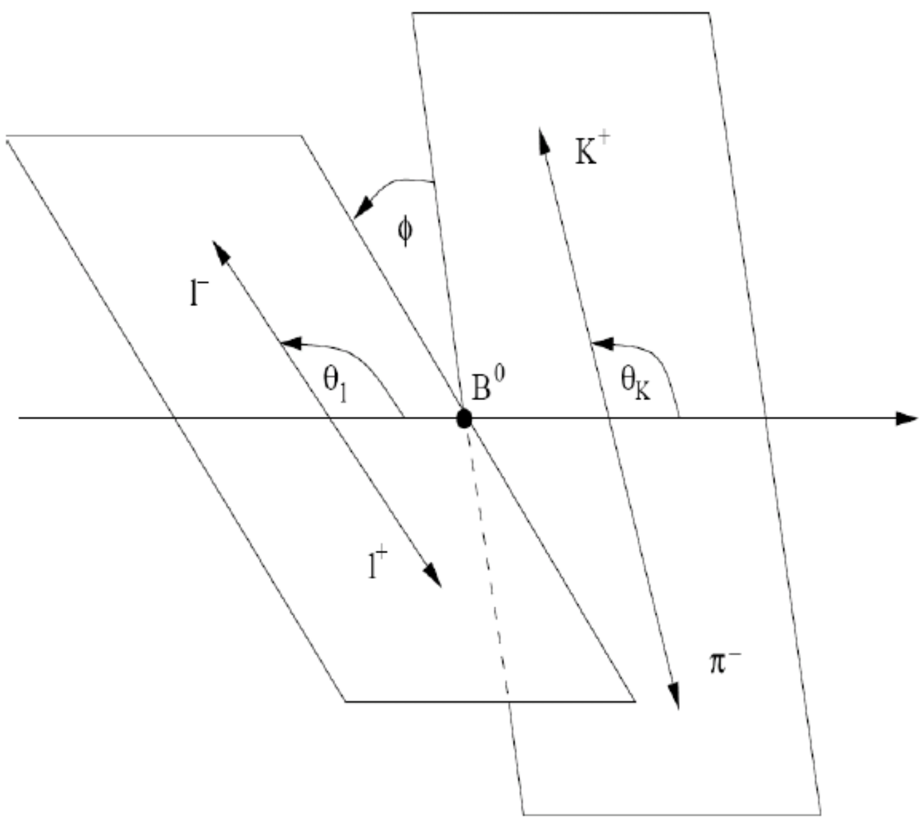


Photon contribution dominates at $M_{e^+e^-} \sim 0$

Angular Analysis: transverse asymmetries

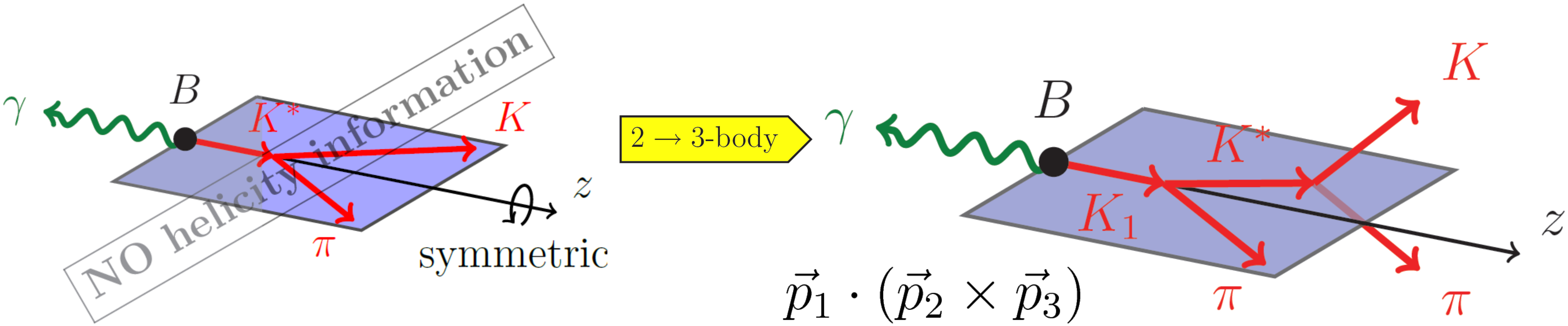
$$A_T^{(2)}(0) = \frac{2Re\left[C_{7\gamma}C_{7\gamma}'^{*}\right]}{|C_{7\gamma}|^2 + |C_{7\gamma}'|^2},$$

$$A_T^{(im)}(0) = \frac{2Im\left[C_{7\gamma}C_{7\gamma}'^{*}\right]}{|C_{7\gamma}|^2 + |C_{7\gamma}'|^2}.$$



Hadronic State Helicity in

$$\bar{B} \to A\gamma \to P_1 P_2 P_3 \gamma$$



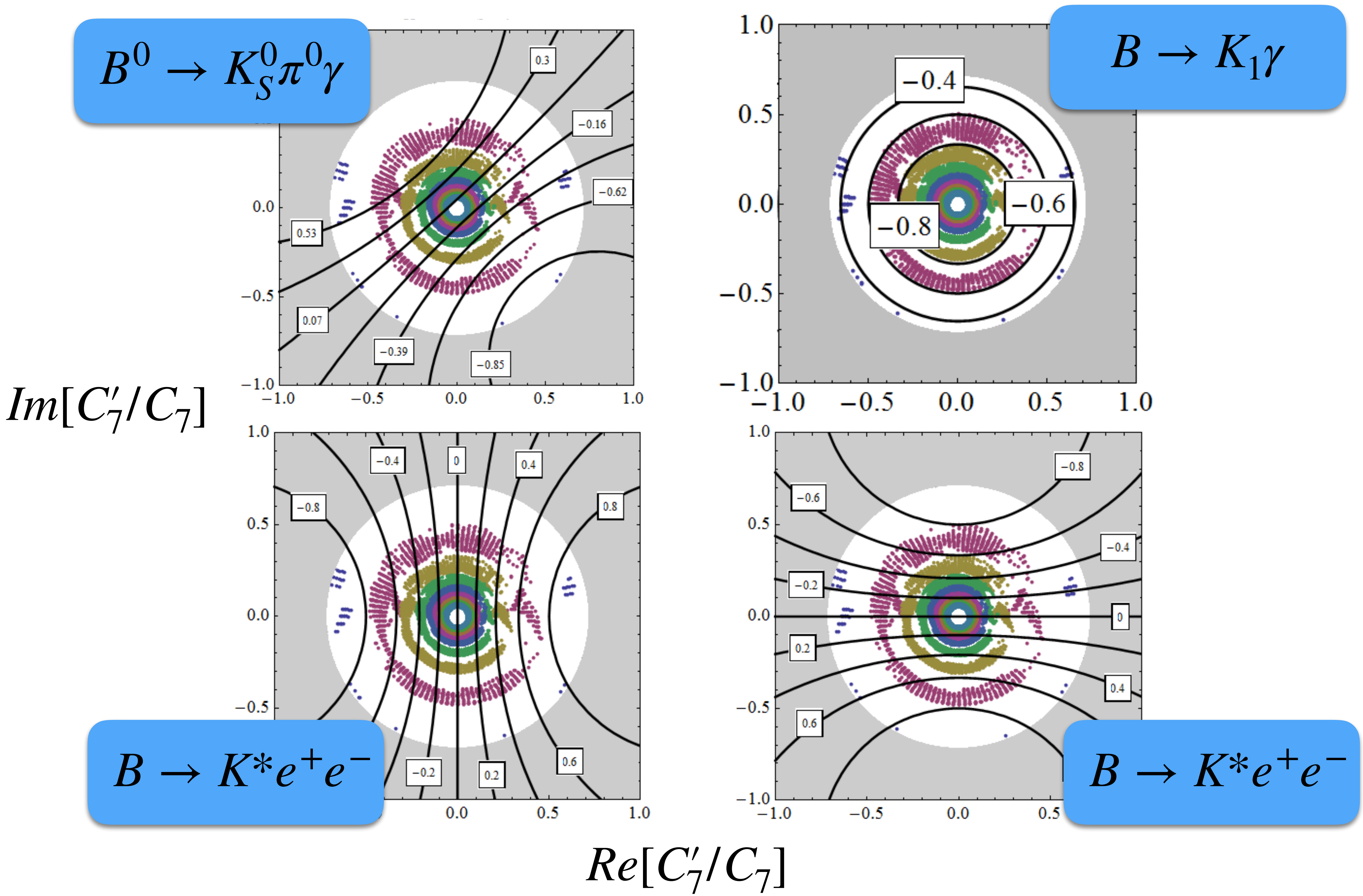
$\bar{B} \to K_1\gamma \to K\pi\pi\gamma$ [Gronau, et al, 2002'; Kou, et al, 2011']

$$\lambda_\gamma \equiv \frac{\left|\mathcal{M}(\overline{B} \to \overline{K}_{1R}\gamma_R)\right|^2 - \left|\mathcal{M}(\overline{B} \to \overline{K}_{1L}\gamma_L)\right|^2}{\left|\mathcal{M}(\overline{B} \to \overline{K}_1\gamma)\right|^2} \approx \frac{\left|C'_{7\gamma}/C_{7\gamma}\right|^2 - 1}{\left|C'_{7\gamma}/C_{7\gamma}\right|^2 + 1}$$

LHCb2014: $$\mathcal{A}_{\rm UD} \equiv \frac{\left[\int_0^1 - \int_{-1}^0\right] d\cos\theta_K \frac{d\Gamma(B\to K_1\gamma)}{d\cos\theta_K}}{\left[\int_0^1 + \int_{-1}^0\right] d\cos\theta_K \frac{d\Gamma(B\to K_1\gamma)}{d\cos\theta_K}} = \lambda_\gamma \frac{3}{4}\frac{\mathrm{Im}[\vec{n}\cdot(\vec{J}\times\vec{J}^*)]}{|\vec{J}|^2}$$

$$= (6.9 \pm 1.7) \times 10^{-2}$$

See W.Wang's talk



FSY, Kou, C.D.Lu, JHEP (1305.3173)

Time-dependent CPA in

$$B^0 \to K_S^0 \pi^+ \pi^- \gamma$$

$$
\begin{array}{ccccc}
 & & B^0 \stackrel{c'(c)}{\longrightarrow} K_{\rm res}\gamma_{L(R)} & & \\
 & f_+(t) \nearrow & & \searrow & \\
B^0(t=0) & & & & (n\pi)K_S^0\gamma_{L(R)} \\
 & \frac{q}{p} f_-(t) \searrow & & \nearrow & \\
 & & \overline{B}^0 \stackrel{c(c')}{\longrightarrow} \overline{K}_{\rm res}\gamma_{L(R)} & &
\end{array}
$$

In the SM, c’/c~ms/mb~0, interference->0

If observed non-zero CPA, signal NP

Time-dependent CPA of $B^0 \to K_S^0 \rho^0 \gamma$

$$\frac{\overline{\Gamma}_{\rho^0 K_S^0 \gamma}(t) - \Gamma_{\rho^0 K_S^0 \gamma}(t)}{\overline{\Gamma}_{\rho^0 K_S^0 \gamma}(t) + \Gamma_{\rho^0 K_S^0 \gamma}(t)} \equiv \mathcal{S}_{\rho^0 K_S^0 \gamma} \sin(\Delta m t) - \mathcal{C}_{\rho^0 K_S^0 \gamma} \cos(\Delta m t)$$

$$\mathcal{S}_{\rho^0 K_S^0 \gamma} = \frac{2\mathrm{Im}\left(\frac{q}{p}\int \sum_{\lambda=L,R}\left[M_\lambda^{*\rho^0 K_S^0}\overline{M}_\lambda^{\rho^0 K_S^0}\right] dp\right)}{\int \sum_{\lambda=L,R}\left[\left|\overline{M}_\lambda^{\rho^0 K_S^0}\right|^2 + \left|M_\lambda^{\rho^0 K_S^0}\right|^2\right] dp}$$

$$\mathcal{S}_{\rho^0 K_S^0 \gamma} = -\frac{2\mathrm{Im}\left(\frac{q}{p} c c'\right)}{|c|^2 + |c'|^2} \qquad \mathcal{S}_{\rho^0 K_S^0 \gamma} = -\mathcal{S}_{\pi^0 K_S^0 \gamma}$$

Time-dependent CPA of $B^0 \to K_S^0 \pi^+ \pi^- \gamma$

more intermediate states

$$B^0 \to K_{\rm res}\gamma \to (\rho^0 K_S^0)\gamma \to K_S^0(\pi^+\pi^-)\gamma,$$
$$B^0 \to K_{\rm res}\gamma \to (K^{*+}\pi^-)\gamma \to (K_S^0\pi^+)\pi^-\gamma,$$
$$B^0 \to K_{\rm res}\gamma \to ((K\pi)_0^+\pi^-)\gamma \to (K_S^0\pi^+)\pi^-\gamma,$$

$$\frac{\overline{\Gamma}_{\pi^+\pi^-K_S^0\gamma}(t) - \Gamma_{\pi^+\pi^-K_S^0\gamma}(t)}{\overline{\Gamma}_{\pi^+\pi^-K_S^0\gamma}(t) + \Gamma_{\pi^+\pi^-K_S^0\gamma}(t)} \equiv \mathcal{S}_{\pi^+\pi^-K_S^0\gamma}\sin(\Delta m t) - \mathcal{C}_{\pi^+\pi^-K_S^0\gamma}\cos(\Delta m t)$$

$S_{\pi^+\pi^-K_S^0\gamma}$ -> measurement

$S_{\rho^0 K_S^0\gamma}$ -> purpose

Dilution factor

$$\mathcal{D} \equiv \frac{\mathcal{S}_{\pi^+\pi^-K_S^0\gamma}}{\mathcal{S}_{\rho^0 K_S^0\gamma}}$$

Time-dependent CPA of $B^0 \to K_S^0 \pi^+ \pi^- \gamma$

$$B^0 \to K_{\rm res}\gamma \to (\rho^0 K_S^0)\gamma \to K_S^0(\pi^+\pi^-)\gamma,$$
$$B^0 \to K_{\rm res}\gamma \to (K^{*+}\pi^-)\gamma \to (K_S^0\pi^+)\pi^-\gamma,$$
$$B^0 \to K_{\rm res}\gamma \to ((K\pi)_0^+\pi^-)\gamma \to (K_S^0\pi^+)\pi^-\gamma,$$

$$\frac{\overline{\Gamma}_{\pi^+\pi^-K_S^0\gamma}(t) - \Gamma_{\pi^+\pi^-K_S^0\gamma}(t)}{\overline{\Gamma}_{\pi^+\pi^-K_S^0\gamma}(t) + \Gamma_{\pi^+\pi^-K_S^0\gamma}(t)} \equiv \mathcal{S}_{\pi^+\pi^-K_S^0\gamma}\sin(\Delta m t) - \mathcal{C}_{\pi^+\pi^-K_S^0\gamma}\cos(\Delta m t)$$

$$\mathcal{S}_{\pi^+\pi^-K_S^0\gamma} = \frac{2\mathrm{Im}\left(\frac{q}{p}\int \sum_{\lambda=L,R}\left[M_\lambda^* \overline{M}_\lambda\right] dp\right)}{\int \sum_{\lambda=L,R}\left[\left|\overline{M}_\lambda\right|^2 + |M_\lambda|^2\right] dp}$$

$$M_\lambda = M_\lambda^{\rho^0 K_S^0} + M_\lambda^{K^{*+}\pi^-} + M_\lambda^{(K\pi)_0^+\pi^-}$$

Relations between amplitudes

$$M_\lambda = M_\lambda^{\rho^0 K_S^0} + M_\lambda^{K^{*+}\pi^-} + M_\lambda^{(K\pi)_0^+\pi^-}$$

$$= A_\lambda \times \left(\mathcal{A}_\lambda^{\rho^0 K_S^0} + \mathcal{A}_\lambda^{K^{*+}\pi^-} + \mathcal{A}_\lambda^{(K\pi)_0^+\pi^-} \right)$$

$\lambda = L, R$

$B \to K_{res}\gamma$

$K_{res} \to \rho K_s,\ K^*\pi,\ (K\pi)_0\pi$

Relations between amplitudes

$B \to K_{\text{res}}\gamma$ amplitudes

$$\overline{A}_R = \langle \overline{K}_{\text{res}}\gamma_R | \mathcal{H}^- | \overline{B} \rangle, \quad \overline{A}_L = \langle \overline{K}_{\text{res}}\gamma_L | \mathcal{H}^+ | \overline{B} \rangle,$$

$$A_R = \langle K_{\text{res}}\gamma_R | \mathcal{H}^{+\dagger} | B \rangle, \quad A_L = \langle K_{\text{res}}\gamma_L | \mathcal{H}^{-\dagger} | B \rangle,$$

$$\overline{A}_R = \langle \overline{K}_{\text{res}}\gamma_R | \mathcal{P}^\dagger \mathcal{P} \mathcal{H}^- \mathcal{P}^\dagger \mathcal{P} | \overline{B} \rangle \;= + \left(\frac{c'}{c}\right) \overline{A}_L,$$

$$\overline{A}_R = \langle \overline{K}_{\text{res}}\gamma_R | \mathcal{C}^\dagger \mathcal{C} \mathcal{H}^- \mathcal{C}^\dagger \mathcal{C} | \overline{B} \rangle \;= + \left(\frac{c'}{c^*}\right) A_R,$$

$$\boxed{\begin{aligned} \overline{A}_R &= +\left(\frac{c'}{c}\right)\overline{A}_L, & A_R &= +\left(\frac{c^*}{c'^*}\right) A_L, \\ \overline{A}_R &= +\left(\frac{c'}{c^*}\right) A_R, & \overline{A}_L &= +\left(\frac{c}{c'^*}\right) A_L. \end{aligned}}$$

Relations between amplitudes

$$\boldsymbol{K_{\mathrm{res}} \to \pi^+\pi^- K_S^0}\ \textbf{amplitudes}$$

$$\mathcal{A}_\lambda^{\rho^0 K_S^0} = \langle \pi^+(p_1)\pi^-(p_2)|\mathcal{H}_s'|\rho^0\rangle\langle\rho^0 K_S^0(p_3)|\mathcal{H}_s|K_{\mathrm{res}}\rangle,$$

$$\overline{\mathcal{A}}_\lambda^{\rho^0 K_S^0} = \langle \pi^+(p_1)\pi^-(p_2)|\mathcal{H}_s'|\rho^0\rangle\langle\rho^0 K_S^0(p_3)|\mathcal{H}_s|\overline{K}_{\mathrm{res}}\rangle,$$

$$\mathcal{A}_\lambda^{\rho^0 K_S^0} = \quad \langle \pi^+(p_1)\pi^-(p_2)|\mathcal{C}^\dagger\mathcal{C}\mathcal{H}_s'\mathcal{C}^\dagger\mathcal{C}|\rho^0\rangle\langle\rho^0 K_S^0(p_3)|\mathcal{C}^\dagger\mathcal{C}\mathcal{H}_s\mathcal{C}^\dagger\mathcal{C}|K_{\mathrm{res}}\rangle$$

$$\boxed{\mathcal{A}_\lambda^{\rho^0 K_S^0}(p_1,p_2,p_3) = \quad \overline{\mathcal{A}}_\lambda^{\rho^0 K_S^0}(p_2,p_1,p_3) \quad = -\overline{\mathcal{A}}_\lambda^{\rho^0 K_S^0}(p_1,p_2,p_3)}$$

$$\mathcal{A}_\lambda^{K^{*+}\pi^-}(p_1,p_2,p_3) \quad = \overline{\mathcal{A}}_\lambda^{K^{*-}\pi^+}(p_2,p_1,p_3)$$

Experimental Strategies (I)

limited-size data sample

phase-space integrated analysis

$$\mathcal{S}_{\pi^+\pi^- K_S^0\gamma} = \frac{2\mathrm{Im}\left(\frac{q}{p}cc'\right)}{|c|^2 + |c'|^2} \frac{\int_{\mathrm{tot}} \mathrm{Re}\left(\mathcal{A}^*(p_1, p_2, p_3)\mathcal{A}(p_2, p_1, p_3)\right)dp}{\int_{\mathrm{tot}} |\mathcal{A}(p_1, p_2, p_3)|^2 dp}$$

Dilution factor

$$\mathcal{D} \equiv \frac{\mathcal{S}_{\pi^+\pi^- K_S^0\gamma}}{\mathcal{S}_{\rho^0 K_S^0\gamma}} = -\frac{\int_{\mathrm{tot}} \mathrm{Re}\left(\mathcal{A}^*(p_1, p_2, p_3)\mathcal{A}(p_2, p_1, p_3)\right)dp}{\int_{\mathrm{tot}} |\mathcal{A}(p_1, p_2, p_3)|^2 dp}$$

Experimental Strategies (I)

Dilution factor

$$\mathcal{D} \equiv \frac{\mathcal{S}_{\pi^+\pi^- K_S^0\gamma}}{\mathcal{S}_{\rho^0 K_S^0\gamma}} = -\frac{\int_{\rm tot} \mathrm{Re}\left(\mathcal{A}^*(p_1, p_2, p_3)\mathcal{A}(p_2, p_1, p_3)\right) dp}{\int_{\rm tot} |\mathcal{A}(p_1, p_2, p_3)|^2 dp}$$

Isospin symmetry -> Large data sample from

$$B^+ \to K_{\rm res}^+\gamma \to K^+\pi^-\pi^+\gamma$$

LHCb

Better reconstruction efficiencies

Experimental Strategies (II)

sizable data sample

time-dependent amplitude analysis

In the Dalitz plane

$$\mathcal{S}^{\delta p}_{\pi^+\pi^- K^0_S\gamma} = 4\mathrm{Im}\left(\frac{q}{p}\frac{\xi}{1+|\xi|^2}\frac{\int_{\delta p}\mathcal{A}^*_{123}\mathcal{A}_{213}dp}{\int_{\delta p}|\mathcal{A}_{123}|^2+|\mathcal{A}_{213}|^2\,dp}\right)$$

$$\mathcal{A}^*_{123}\mathcal{A}_{213} = \sum_{i,j}\left[\mathcal{A}^{*i}(p_1,p_2,p_3)\mathcal{A}^j(p_2,p_1,p_3)\right]$$

$$\frac{\xi}{1+|\xi|^2} = \frac{cc'}{|c|^2+|c'|^2} \qquad \xi \equiv c'/c^*$$

Time-dependent amplitude analysis

$$\boxed{\mathcal{S}^{\delta p}_{\pi^+\pi^- K^0_S\gamma} = 4\mathrm{Im}\left(\frac{q}{p}\frac{\xi}{1+|\xi|^2}\frac{\int_{\delta p}\mathcal{A}^*_{123}\mathcal{A}_{213}dp}{\int_{\delta p}|\mathcal{A}_{123}|^2+|\mathcal{A}_{213}|^2\,dp}\right)}$$

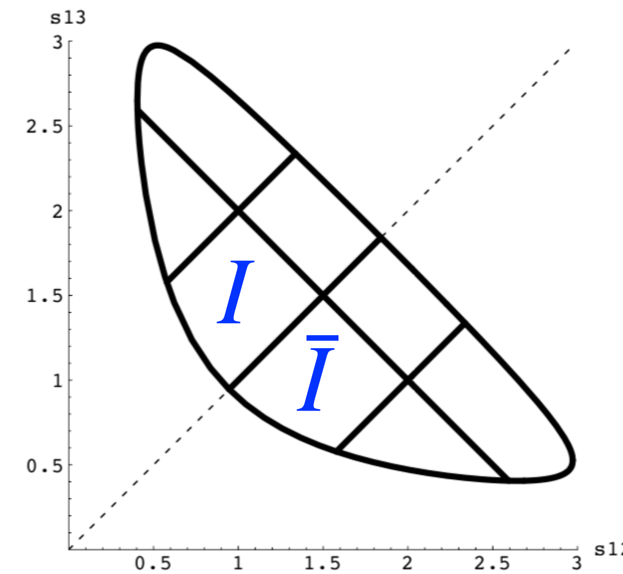
$$\mathcal{A}_{123} = |\mathcal{A}_{123}|\,e^{i\delta^p_{123}}, \qquad \mathcal{A}_{213} = |\mathcal{A}_{213}|\,e^{i\delta^p_{213}}$$

$$\frac{\int_{\delta p}\mathcal{A}^*_{123}\mathcal{A}_{213}dp}{\int_{\delta p}|\mathcal{A}_{123}|^2+|\mathcal{A}_{213}|^2\,dp} = \underbrace{\frac{\int_{\delta p}|\mathcal{A}_{123}|\,|\mathcal{A}_{213}|\cos(\delta^p_{213}-\delta^p_{123})dp}{\int_{\delta p}|\mathcal{A}_{123}|^2+|\mathcal{A}_{213}|^2\,dp}}_{\equiv\,\mathrm{a}^{\delta p}} + i\underbrace{\frac{\int_{\delta p}|\mathcal{A}_{123}|\,|\mathcal{A}_{213}|\sin(\delta^p_{213}-\delta^p_{123})dp}{\int_{\delta p}|\mathcal{A}_{123}|^2+|\mathcal{A}_{213}|^2\,dp}}_{\equiv\,\mathrm{b}^{\delta p}},$$

real part   imaginary part

Time-dependent amplitude analysis

Define symmetric region of the Dalitz plot



$$\mathcal{S}^+ \equiv \mathcal{S}^{I}_{\pi^+\pi^- K^0_S\gamma} + \mathcal{S}^{\overline{I}}_{\pi^+\pi^- K^0_S\gamma} = \frac{8}{1+|\xi|^2}\left(\mathrm{Im}\xi\cos 2\beta - \mathrm{Re}\xi\sin 2\beta\right)\mathrm{a}^I,$$

$$\mathcal{S}^- \equiv \mathcal{S}^{I}_{\pi^+\pi^- K^0_S\gamma} - \mathcal{S}^{\overline{I}}_{\pi^+\pi^- K^0_S\gamma} = \frac{8}{1+|\xi|^2}\left(\mathrm{Re}\xi\cos 2\beta + \mathrm{Im}\xi\sin 2\beta\right)\mathrm{b}^I.$$

$$\frac{\mathrm{Re}\xi}{1+|\xi|^2} = \frac{1}{8}\left(\frac{\mathcal{S}^-}{\mathrm{b}^I}\cos 2\beta - \frac{\mathcal{S}^+}{\mathrm{a}^I}\sin 2\beta\right)$$

$$\frac{\mathrm{Im}\xi}{1+|\xi|^2} = \frac{1}{8}\left(\frac{\mathcal{S}^-}{\mathrm{b}^I}\sin 2\beta + \frac{\mathcal{S}^+}{\mathrm{a}^I}\cos 2\beta\right)$$

$$\frac{\xi}{1+|\xi|^2} = \frac{cc'}{|c|^2+|c'|^2}$$

$$\xi \equiv c'/c^*$$

Time-dependent amplitude analysis

$$\frac{\mathrm{Re}\xi}{1+|\xi|^2} = \frac{1}{8}\left(\frac{\mathcal{S}^-}{\mathrm{b}^I}\cos 2\beta - \frac{\mathcal{S}^+}{\mathrm{a}^I}\sin 2\beta\right)$$

$$\frac{\mathrm{Im}\xi}{1+|\xi|^2} = \frac{1}{8}\left(\frac{\mathcal{S}^-}{\mathrm{b}^I}\sin 2\beta + \frac{\mathcal{S}^+}{\mathrm{a}^I}\cos 2\beta\right)$$

$$\frac{\xi}{1+|\xi|^2} = \frac{cc'}{|c|^2+|c'|^2}$$

$$\xi \equiv c'/c^*$$

To be measured:

$$\mathcal{S}^+ \equiv \mathcal{S}^I_{\pi^+\pi^-K^0_S\gamma} + \mathcal{S}^{\overline{I}}_{\pi^+\pi^-K^0_S\gamma}$$

$$\mathcal{S}^- \equiv \mathcal{S}^I_{\pi^+\pi^-K^0_S\gamma} - \mathcal{S}^{\overline{I}}_{\pi^+\pi^-K^0_S\gamma}$$

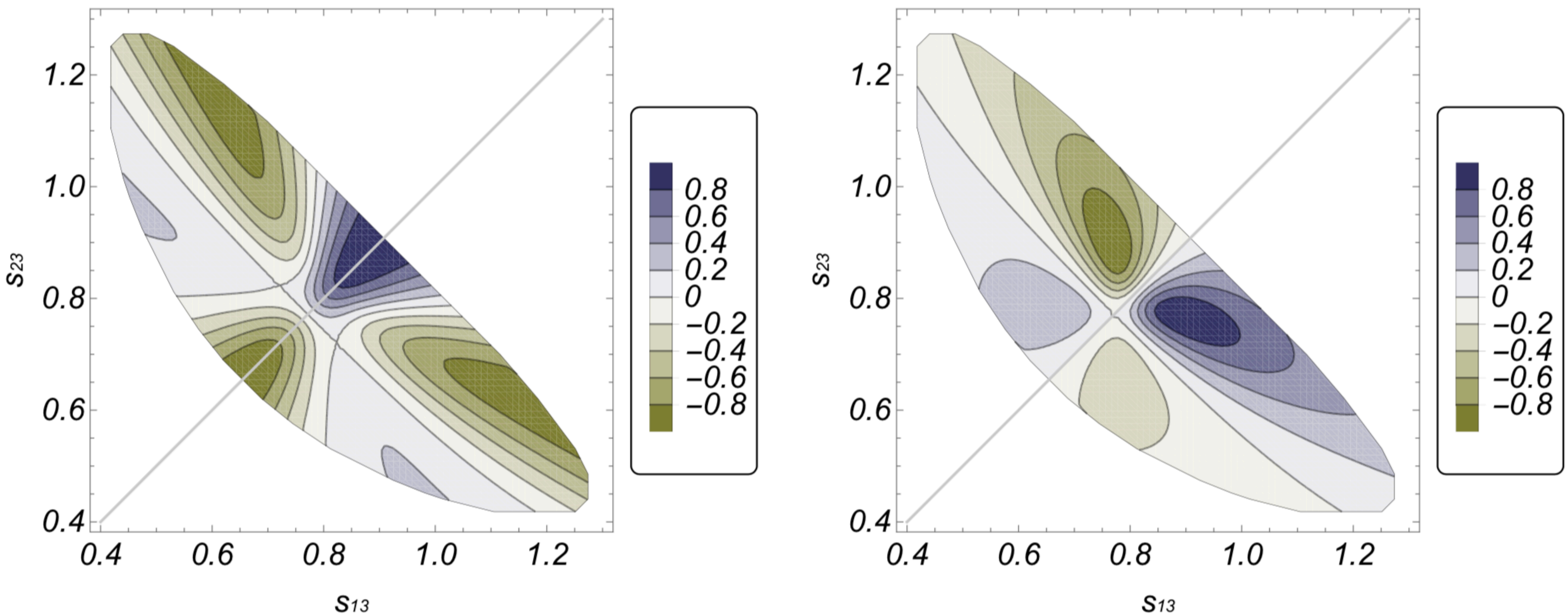
a^I and b^I from $B^+ \to K^+_{\mathrm{res}}\gamma \to K^+\pi^-\pi^+\gamma$

Summary

- Photon polarization in b->s gamma is useful to search for new physics
- Methods proposed to measure photon polarization in B->Ks pi pi gamma

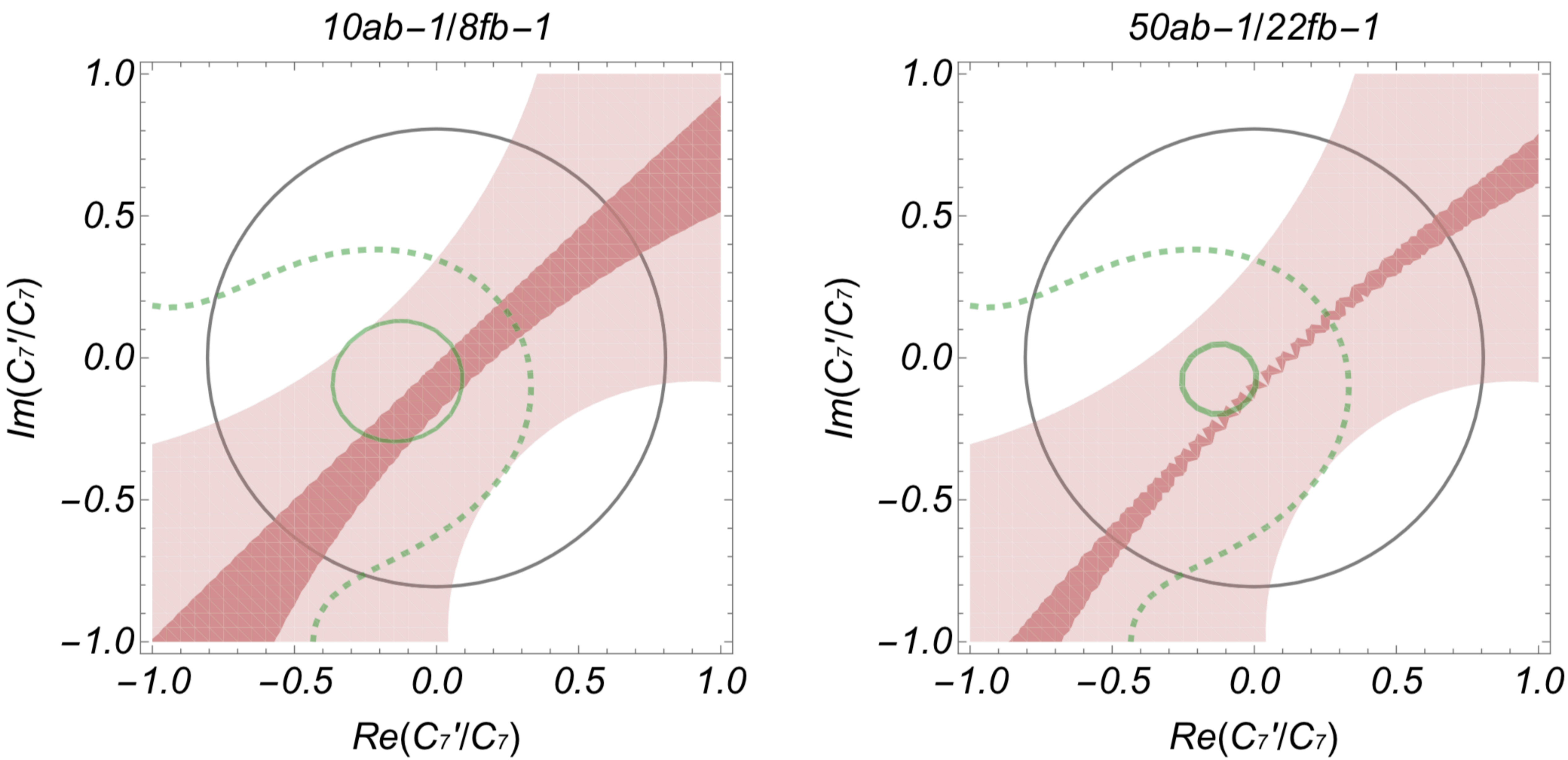
Thank you!

Backups

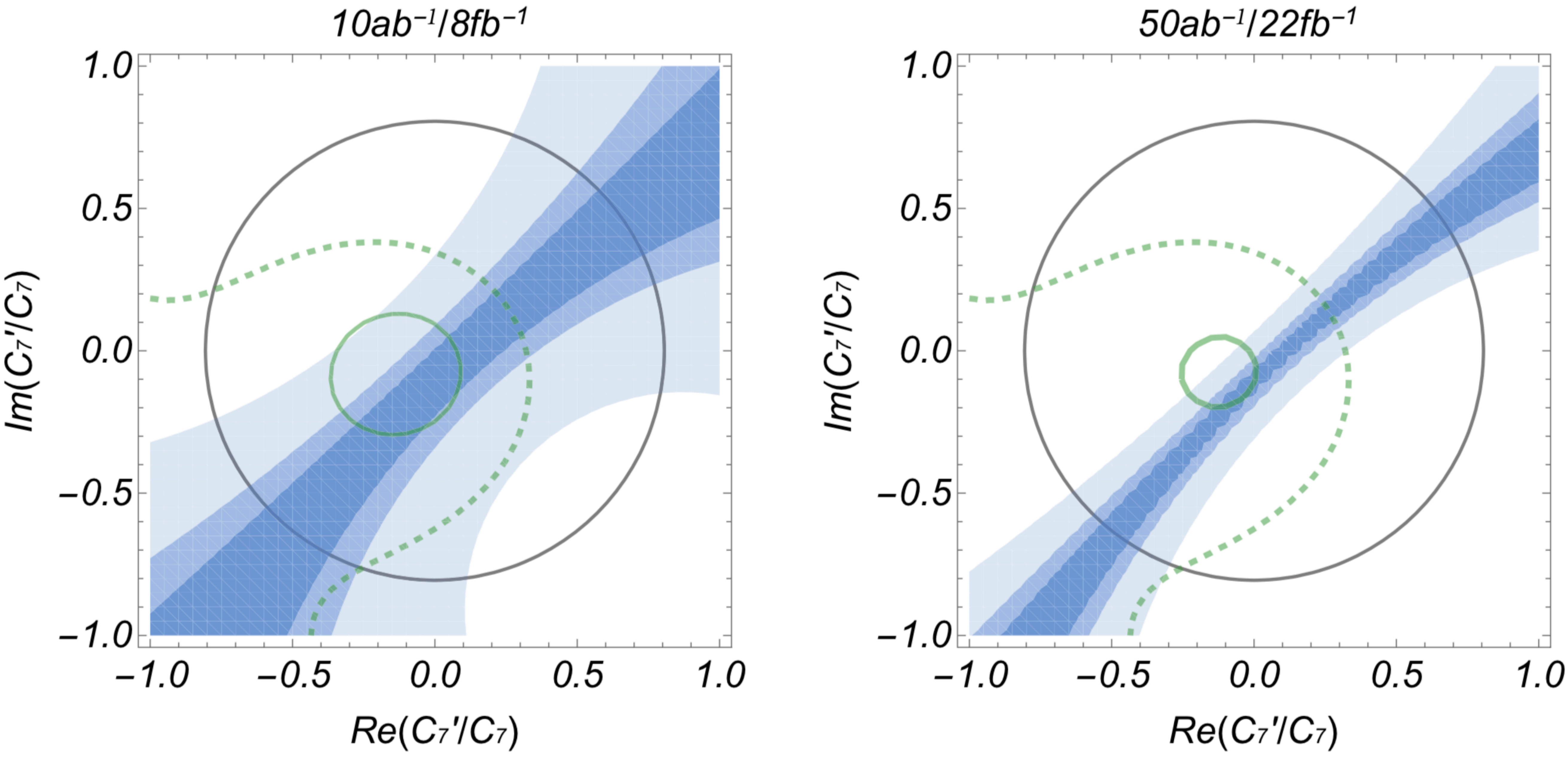


0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
1.2
1.0
0.8
0.6
0.4
0.4
0.6
0.8
1.0
1.2
s23
s13

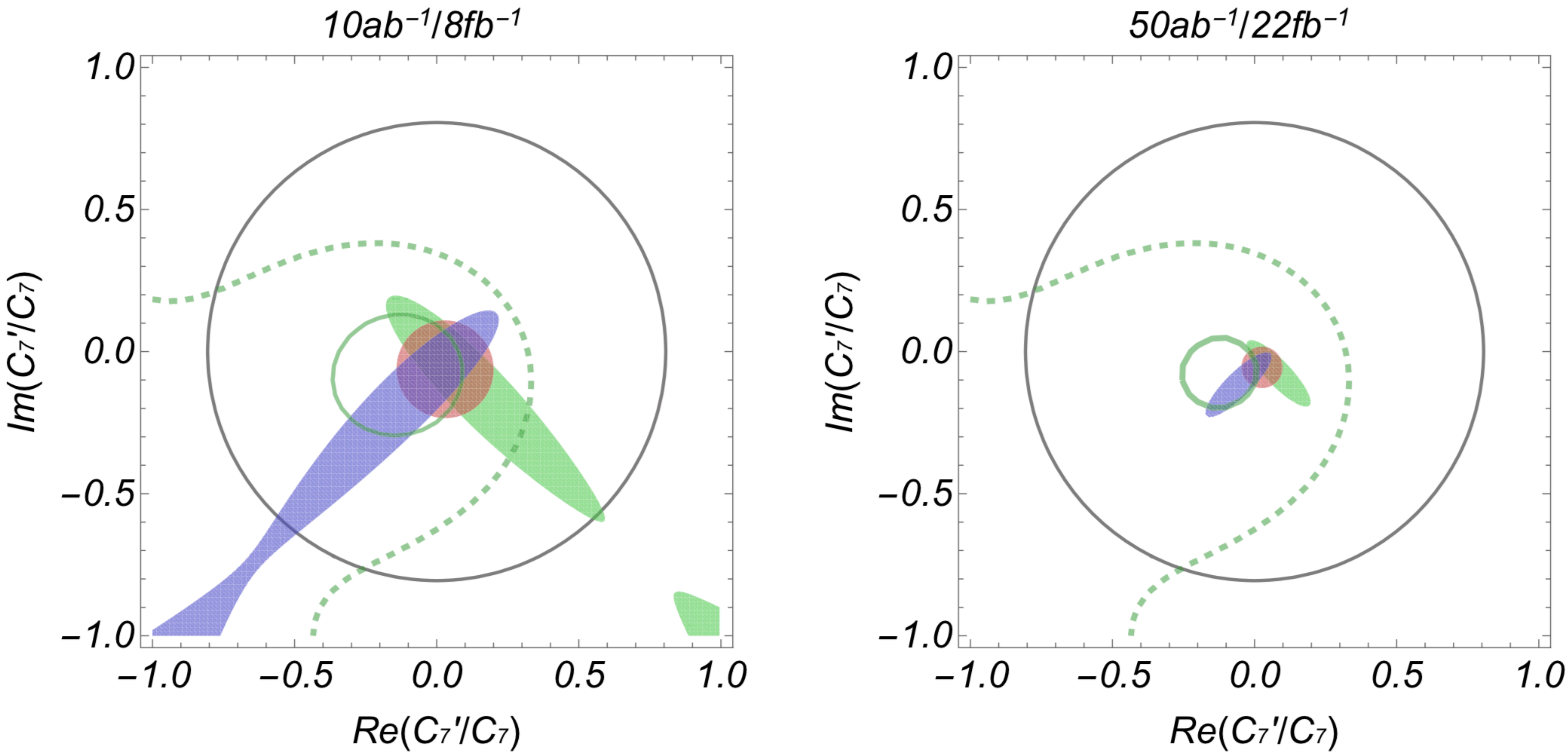
B-> KS pi0 gamma



phase-space integrated analysis



Time-dependent amplitude analysis



Outline

1. Heavy quark physics
2. Photon polarization of $b \to s\gamma$
3. Progresses on measurements
4. Model-independent method to determine hadronic information

- Indirect search for NP
- Sensitive to NP
- $B \to K_1\gamma \to K\pi\pi\gamma$
- $D \to K_1 e\nu \to K\pi\pi e\nu$

1. Indirect search for BSM

- Tiny branching fraction of $K_L^0 \to \mu^+\mu^-$
  - ✓ Predict **charm quark** (Glashow, Iliopoulos, Maiani, 1970)
- Frequency of $K^0 - \overline{K}^0$ oscillation
  - ✓ Predict **charm quark mass** (Gaillard, Lee, 1974)

▶ **Discovery of charm quark** (BNL, SLAC, 1974)

- CP violation in $K_L^0 \to \pi\pi$
  - ✓ Predict **3rd generation** quarks (Kobayashi, Maskawa, 1973)
- Frequency of $B^0 - \overline{B}^0$ oscillation
  - ✓ Predict **top quark mass** (late 1980's)

▶ **Discovery of bottom quark** (Fermilab, 1977)

▶ **Discovery of top quark** (Fermilab, 1995)

1. Heavy quark physics

Intensity frontier for BSM

- If LHC **NOT discover** any new particle beyond SM, **precision study** becomes an **ideal platform** to detect NP effects.
- If LHC **discover** new elementary particles beyond SM, **precision flavor physics** will be necessary to constrain the underlying **coupling structure**.

2. Photon polarization in $b \to s\gamma$

Sensitive to new physics

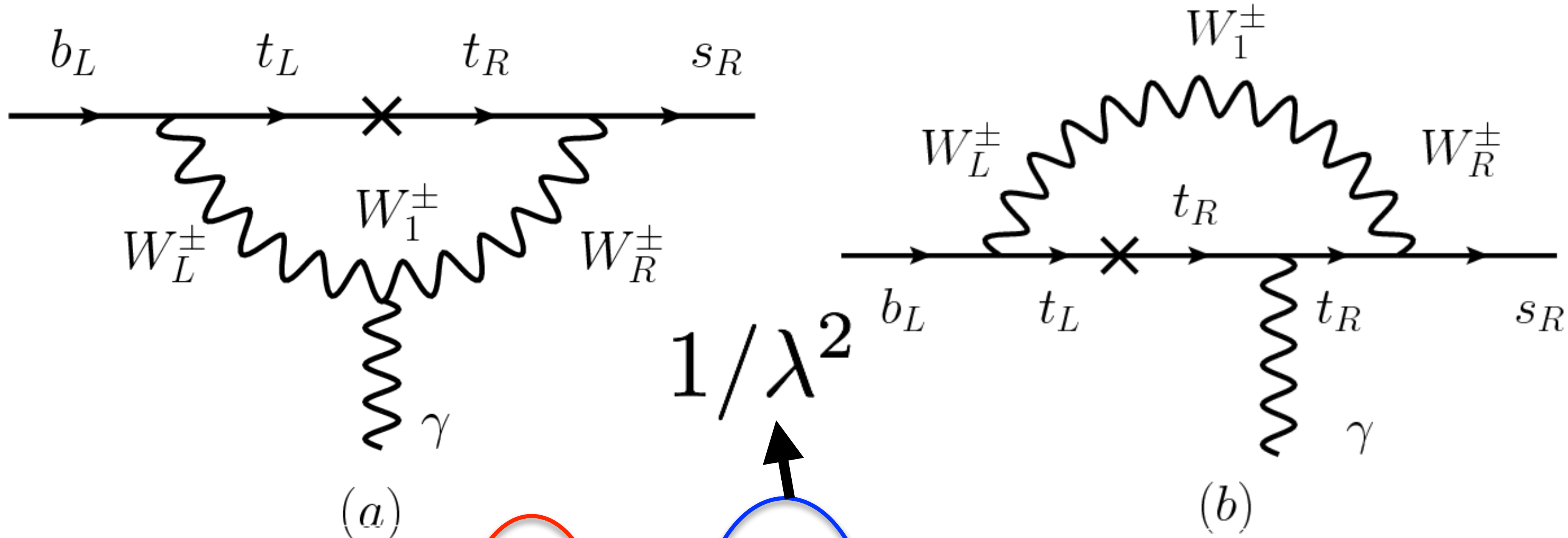
$$A = A_{\rm SM} + A_{\rm NP}$$

$$\Gamma_i \propto |A_{\rm SM} + A_{\rm NP}|^2$$

- If $|A_{\rm NP}| \gg |A_{\rm SM}|$, measuring $\Gamma_i \sim |A_{\rm NP}|^2$
- If $|A_{\rm NP}| \ll |A_{\rm SM}|$, measuring asymmetries

$$\Gamma_i - \overline{\Gamma}_i \propto A_{\rm NP}/A_{\rm SM}$$

Dominant Contribution to Wrong Polarization in LRSM



$$C'_{7\gamma}(\mu_{W_1})_{W_1} = \frac{1}{2}\frac{m_t}{m_b}\frac{g_R^2}{g_L^2}\frac{V_{ts}^{R*}}{V_{ts}^{L*}}\frac{M_{W_1}^2}{M_{W_2}^2}\sin 2\beta e^{-i\omega} A_{\rm LR}(x_t)$$

In LRSM, wrong polarization is enhanced by two factors

$$\frac{C'_{7\gamma}(\mu_b)}{C_{7\gamma}(\mu_b)} \sim -1180\frac{g_R^2}{g_L^2}\;\frac{M_{W_1}^2}{M_{W_2}^2}\;\sin 2\beta\; V_{ts}^{R*}\; e^{-i\omega}$$