Direct CP asymmetry of $b \to s\gamma$ and $b \to d\gamma$ in models beyond the Standard Model

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We study the direct CP asymmetry of the decays $b \to s\gamma$ and $b \to d\gamma$ in the context of two models: i) a supersymmetric (SUSY) model with unconstrained SUSY phases, and ii) a model with a single generation of vector quarks. Current measurements of the direct CP asymmetry of $b \to s\gamma$ are sensitive to the contribution from $b \to d\gamma$. In both the above models we show that $b \to d\gamma$ can sizeably influence the combined asymmetry, and in case ii) may in fact be the dominant contribution.

A.G. Akeroyd, Y.Y. Keum, S. Recksiegel, Phys. Lett. **B 507**, 252 (2001); A.G. Akeroyd, S. Recksiegel, Phys. Lett. **B 525**, 81 (2002)

Motivation for considering $B \to X_d\gamma$

(i) It provides a theoretically clean way of measuring V_{td}, as proposed in

(ii) $\mathcal{A}_{CP}$ in the SM is sizeable, and much larger than that for $b \to s\gamma$

(iii) The current measurement of $\mathcal{A}_{CP}$ for $b \to s\gamma$ by the CLEO Collaboration is sensitive to events from $b \to d\gamma$. Therefore knowledge of $\mathcal{A}_{CP}$ for $b \to d\gamma$ is essential, in order to compare experimental data with the theoretical prediction in a given model.

(iv) $\mathcal{A}_{CP}$ for the combined signal of $B \to X_s\gamma$ and $B \to X_d\gamma$ is expected to be close to zero in the SM Both of these conditions can be relaxed in models beyond the SM.

$b \to d\gamma$ and $b \to s\gamma$

$$R = \frac{BR(B \to X_d\gamma)}{BR(B \to X_s\gamma)} = 0.017 < R < 0.074 \quad \Rightarrow \quad BR(B \to X_d\gamma) \approx 10^{-5} \to 10^{-6} \tag{1}$$

At B–factories: expect $10^2 \to 10^3$ $b \to d\gamma$ transitions.

$$\mathcal{A}_{CP}^{d\gamma(s\gamma)} = \frac{\Gamma(\overline{B} \to X_{d(s)}\gamma) - \Gamma(B \to X_{\overline{d}(\overline{s})}\gamma)}{\Gamma(\overline{B} \to X_{d(s)}\gamma) + \Gamma(B \to X_{\overline{d}(\overline{s})}\gamma)} = \frac{\Delta\Gamma_{d(s)}}{\Gamma_{d(s)}^{tot}} \tag{2}$$

Expected SM range: $-5\% \leq \mathcal{A}_{CP}^{d\gamma} \leq -28\%$

Isolating $B \to X_d\gamma$ is challenging since $B \to X_s\gamma$ constitutes serious background. If $\mathcal{A}_{CP}^{d\gamma}$ and $\mathcal{A}_{CP}^{s\gamma}$ cannot be separated, then only their sum can be measured. In SM (with $m_s = m_d = 0$) unitarity of the CKM matrix ensures that the sum is zero. In the presence of new physics this cancellation does not occur.

CLEO measures weighted sum of CP asymmetries:

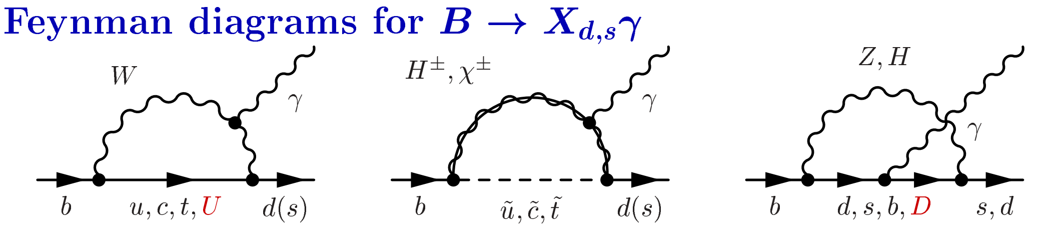
$$\mathcal{A}_{CP}^{exp} = 0.965\mathcal{A}_{CP}^{s\gamma} + 0.02\mathcal{A}_{CP}^{d\gamma} = -27\% < \mathcal{A}_{CP}^{exp} < 10\% (90\% c.l.). \tag{3}$$

If the detection efficiencies for both decays were identical, this would coincide with

$$\mathcal{A}_{CP}^{s\gamma+d\gamma} = \frac{\mathrm{BR}^{s\gamma}\mathcal{A}_{CP}^{s\gamma} + \mathrm{BR}^{d\gamma}\mathcal{A}_{CP}^{d\gamma}}{\mathrm{BR}^{s\gamma} + \mathrm{BR}^{d\gamma}}. \tag{4}$$

$\longrightarrow$ need to consider $B \to X_d\gamma$ contribution to $\mathcal{A}_{CP}^{exp}$!

Feynman diagrams for $B \to X_{d,s}\gamma$



Direct CP Asymmetry in $B \to X_{d,s}\gamma$

$$\mathcal{H}_{eff} = -\frac{4G_F}{\sqrt{2}} V_{td}^* V_{tb} \sum_{i=1}^{8} C_i(\mu_b) Q_i(\mu_b), \qquad Q_7 = \frac{e}{16\pi^2} m_b \bar{d}_L \sigma^{\mu\nu} b_R F_{\mu\nu}, \tag{5}$$

$$\mathcal{A}_{CP}^{d(s)\gamma} = \frac{10^{-2}}{|C_7|^2}\Big(1.17 \times \mathrm{Im}[C_2 C_7^*] - 9.51 \times \mathrm{Im}[C_8 C_7^*] + 0.12 \times \mathrm{Im}[C_2 C_8^*] - 9.40 \times \mathrm{Im}[\epsilon_{d(s)} C_2 (C_7^* - 0.013 C_8^*)]\Big) \tag{6}$$

$$\epsilon_x = V_{ux}^* V_{ub} / V_{tx}^* V_{tb} \tag{7}$$

In the SM $Im(C_x) = 0$, only last term contributes $\longrightarrow$ cancellation (CKM–unitarity)

Numerics

Effective SUSY Model parameters are varied in the range

	M	M'	$\tan\beta$	$m_{H^\pm}$	M_Q	M_U	μ	ϕ_μ	A_t	ϕ_A	ρ	η
min	0	0	1	200	0	0	0	0	0	0	-0.1	0.2
max	400	400	30	500	200	200	200	2π	300	2π	0.4	0.5

EDM constraints automatically fulfilled, direct search lower limits on the masses of $\tilde{t}_1$ and $\chi^\pm$ fulfilled by discarding points that do not pass cuts $m_{\tilde{t}_1} > 90$ GeV and $m_{\chi_1^\pm} > 80$ GeV, furthermore $0.2 \leq |C_7(m_b)| \leq 0.38$.

Vectorquark Model parameters are varied in the range

	ρ	η	$m_{U/D}$	M_H	$\lvert V_{Us}^* V_{Ub}\rvert$	$\lvert V_{Ud}^* V_{Ub}\rvert$	$\lvert z_{sb}\rvert$	$\lvert z_{db}\rvert$	Arg z_{sb}, z_{db}
min	-0.1	0.2	250	100	0	0	0	0	0
max	0.4	0.5	1000	200	0.004	0.008	$8.1\cdot10^{-4}$	0.001	2π

Conclusions

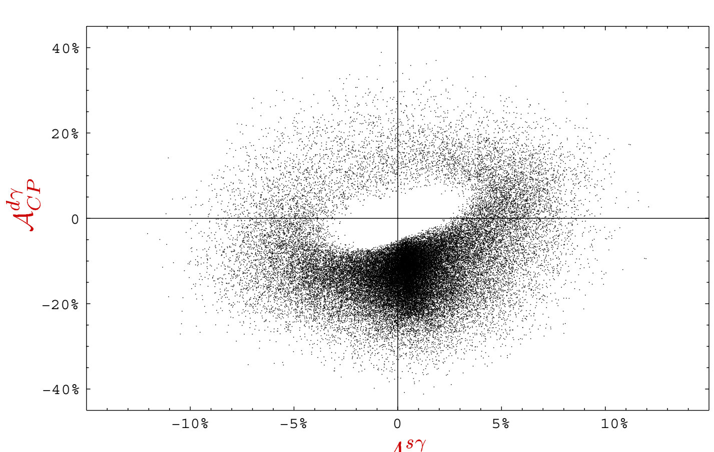
Standard Model: $-28\% \leq \mathcal{A}_{CP}^{d\gamma} \leq -5\%$, $0 < \mathcal{A}_{CP}^{s\gamma} < 1\%$, combined $|\mathcal{A}_{CP}^{s\gamma+d\gamma}| < 0.3\%$.

Effective SUSY Model: $-40\% \leq \mathcal{A}_{CP}^{d\gamma} \leq 40\%$, ($-10\% \leq \mathcal{A}_{CP}^{s\gamma} \leq 10\%$), this has a measurable (at high luminosity B factories) impact on the combined asymmetry. Both constructive and destructive interference possible. R unchanged with respect to SM.

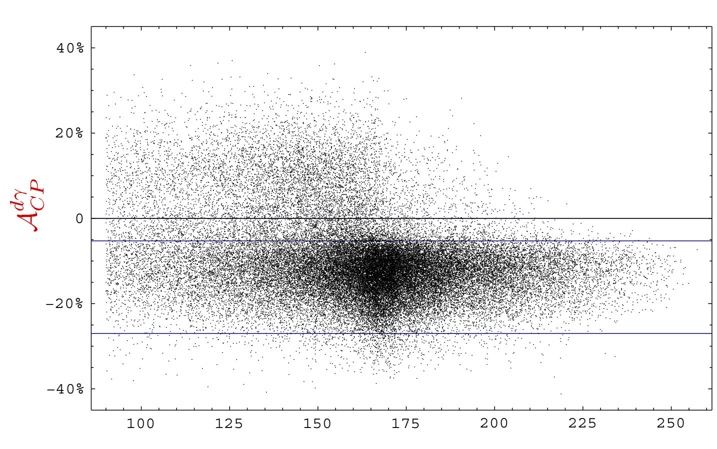
Vector quark Model: $-40\% \leq \mathcal{A}_{CP}^{d\gamma} \leq 40\%$ but $-0.25\% \leq \mathcal{A}_{CP}^{s\gamma} \leq 1.25\%$ almost unchanged. Large effects in combined asymmetry caused by increased $0.01 < R < 0.3$. Combined asymmetry can be dominated by $b \to d\gamma$.

Non–vanishing combined asymmetry $\mathcal{A}_{CP}^{s\gamma+d\gamma}$ is a clear signal of physics beyond the SM. Interpretation crucially depends on excellent K/π–separation.

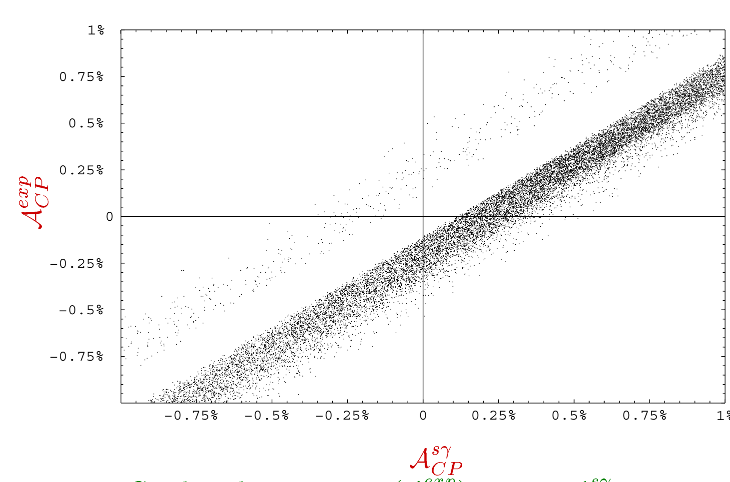
Effective SUSY Model Plots



$\mathcal{A}_{CP}^{d\gamma}$ against $\mathcal{A}_{CP}^{s\gamma}$

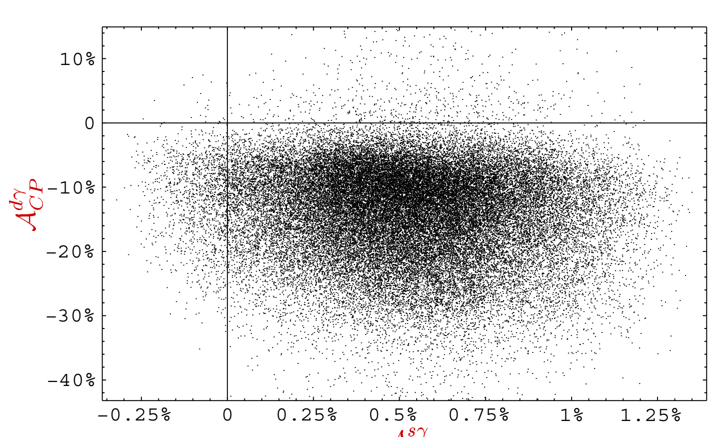


$\mathcal{A}_{CP}^{d\gamma}$ against $m_{\tilde{t}_1}$

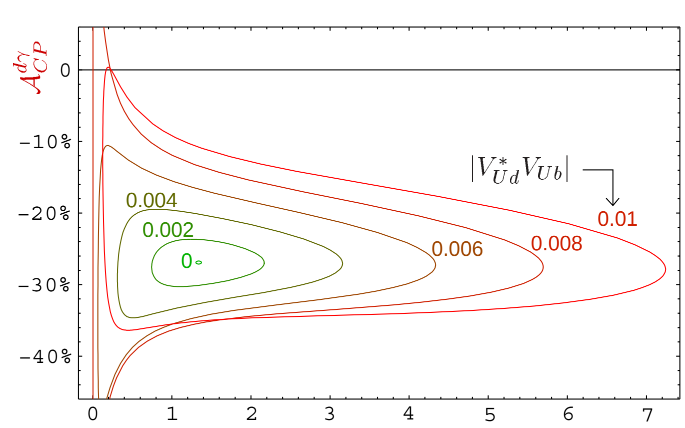


Combined asymmetry ($\mathcal{A}_{CP}^{exp}$) against $\mathcal{A}_{CP}^{s\gamma}$

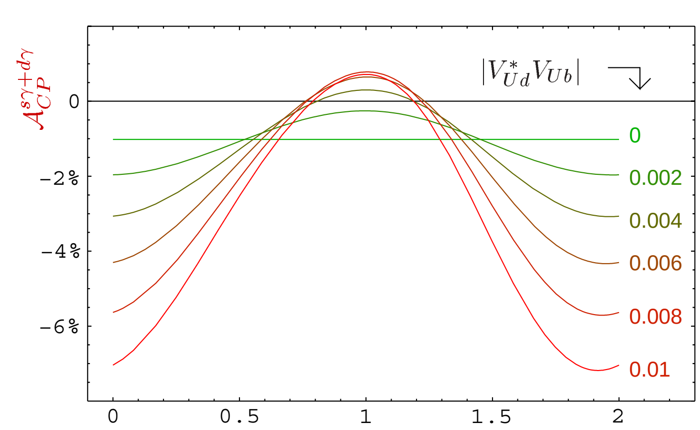
Vector Quark Model Plots



$\mathcal{A}_{CP}^{d\gamma}$ against $\mathcal{A}_{CP}^{s\gamma}$



$\mathcal{A}_{CP}^{d\gamma}$ against $BR(b \to d\gamma)$ for different $|V_{Ud}^* V_{Ub}|$



Combined asymmetry ($\mathcal{A}_{CP}^{s\gamma+d\gamma}$) against Arg $V_{Ud}^* V_{Ub}$