Probing Z-penguins with exclusive $B \to K^* \ell^+ \ell^-$ decays -a model independent analysis

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Outline

- motivation/introduction to FCNC in EFT, focus on $\bar{s}Zb$
- $B \to (X_s, K, K^*)\ell^+\ell^-$ overview
- Forward-Backward (FB) asymmetry in $B \to K^* \ell^+ \ell^-$
- testing $\arg(\bar{s}Zb)$ with FB CP asymmetry in $B \to K^* \ell^+ \ell^-$
- summary

based on:

A. Ali, P.Ball, L.T. Handoko, G.H.(ABHH'99) , hep-ph/9910221, PRD '00
G.Buchalla, G.Isidori, G.H.

low energy EFT for $b \to s(d)$

3 classes of FCNC operators ($\triangle B = 1, 2$):
(where to look for new physics??)

1. 4-Fermi operators: $(\bar{q}\gamma_\mu L b)(\bar{q}\gamma^\mu L b)$
   tested (for $b \to d$) in $B_0 - \bar{B}_0$ mixing
2. magnetic moments operators: $\mathcal{O}_7 \sim \bar{s}\sigma_{\mu\nu} b F^{\mu\nu}$

$$\begin{aligned} \mathcal{B}(B \to X_s \gamma) &= (3.15 \pm 0.35 \pm 0.32 \pm 0.26) \cdot 10^{-4} \\ &\sim |\mathcal{C}_7{}^{\text{eff}}|^2 \end{aligned}$$

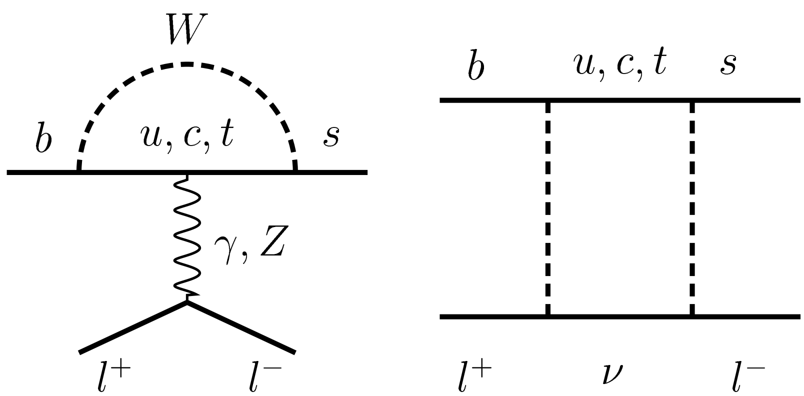
   Cleo '98 sign (phase) of $\mathcal{C}_7{}^{\text{eff}}$ not fixed !
3. Z-penguins $\bar{s}\gamma_\mu b Z^\mu$ dim 4

focus on $\bar{s}_L \gamma_\mu b_L Z^\mu$ $(\bar{s}_R \gamma_\mu b_R Z^\mu)$

- least tested
- sensitivity to higher scales
- many non standard effects possible for $\bar{s}\gamma_\mu b Z^\mu$ in many new physics scenarios (SUSY with $q - \tilde{q}$ not aligned, Z' physics with family non universal couplings, 4th generation ...)

Where can $\bar{s}Zb$ be tested ?

A) $b \to s\ell^+\ell^- \supset \gamma, Z$- penguins, box



B) $b \to s\nu\bar{\nu} \supset$ box, Z- penguin, theoretically very clean, no EM resonances, less operators than A), no γ- penguin

C) $B_s - \bar{B}_s$ mixing

D) $b \to s\bar{q}q$ non leptonic 2-body decays Grossman '99 et al

$B \to (X_s, K, K^*)\ell^+\ell^-$ in the effective Hamiltonian

$$\mathcal{H}_{eff} = -\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \sum_i C_i O_i$$

(unitarity and $V_{us}^* V_{ub} \ll V_{ts}^* V_{tb}$) Buras, Grinstein, Misiak etal

major actors are O_7, O_9, O_{10}

$$\begin{aligned} O_9 &\sim \bar{s}_L \gamma^\mu b_L \bar{\ell} \gamma_\mu \ell & \text{(V)} \\ O_{10} &\sim \bar{s}_L \gamma^\mu b_L \bar{\ell} \gamma_\mu \gamma_5 \ell & \text{(A)} \end{aligned}$$

helicity flipped ones:

$$\begin{aligned} \mathcal{O}_9' &\sim \bar{s}_R \gamma^\mu b_R \bar{\ell} \gamma_\mu \ell \\ \mathcal{O}_{10}' &\sim \bar{s}_R \gamma^\mu b_R \bar{\ell} \gamma_\mu \gamma_5 \ell \end{aligned}$$

charge assignments of lepton-Z-couplings

$$\frac{\mathcal{C}_9{}^{(\prime)}}{\mathcal{C}_{10}{}^{(\prime)}} \sim \frac{\bar{\ell}\ell Z|_V}{\bar{\ell}\ell Z|_A} = \frac{-1/2 + 2\sin^2\Theta_W}{1/2} = -0.11$$

C_{10} probes $\bar{s}_L \gamma_\mu b_L Z^\mu$ modulo the box contribution (20% in the SM)

numbers, bounds

inclusive channels Cleo '98 :

$$\begin{aligned} \mathcal{B}(B \to X_s \mu^+ \mu^-)_{SM} &= 5.7 \pm 1.1 \cdot 10^{-6} \\ \mathcal{B}(B \to X_s \mu^+ \mu^-) &< 5.8 \cdot 10^{-5} \end{aligned}$$

exclusive channels CDF '99:

$$\begin{aligned} \mathcal{B}(B \to K \mu^+ \mu^-)_{SM} &= 5.9 \pm 2.1 \cdot 10^{-7} \\ \mathcal{B}(B^+ \to K^+ \mu^+ \mu^-) &< 5.2 \cdot 10^{-6} \\ \mathcal{B}(B \to K^* \mu^+ \mu^-)_{SM} &= 2.0 \pm 0.7 \cdot 10^{-6} \\ \mathcal{B}(B^0 \to K^{*0} \mu^+ \mu^-) &< 4.0 \cdot 10^{-6} \end{aligned}$$

dominant error from FFs, m_t and renormalization scale μ

$=> B \to K^* \mu^+ \mu^-$ has most interesting bound

model independent analysis

$B \to K^* \mu^+ \mu^-$ branching ratio decomposition ABHH'99

$\mathcal{B} = a|\mathcal{C}_7{}^{\rm eff}|^2 + b|\mathcal{C}_9|^2 + c|\mathcal{C}_{10}|^2 + d\mathcal{C}_7{}^{\rm eff}\mathcal{C}_9 + e\mathcal{C}_7{}^{\rm eff} + f\mathcal{C}_9 + g$

bound from $B \to X_s \gamma$:

$$0.25 \leq |C_7^{eff,LLOG}(\mu = 4.8 \text{ GeV})| \leq 0.37$$

form factors (FF) from light cone sum rules Ball, Braun

$$|C_{10}| \leq 10$$

if we allow in general for right handed O'_{10}: $|C_{10}, C'_{10}| \leq 13$

$C_{10}^{SM} = -4.7$ enhancement maximal factor 2-3 , best bound on $\bar{s}_L \gamma_\mu b_L Z^\mu$

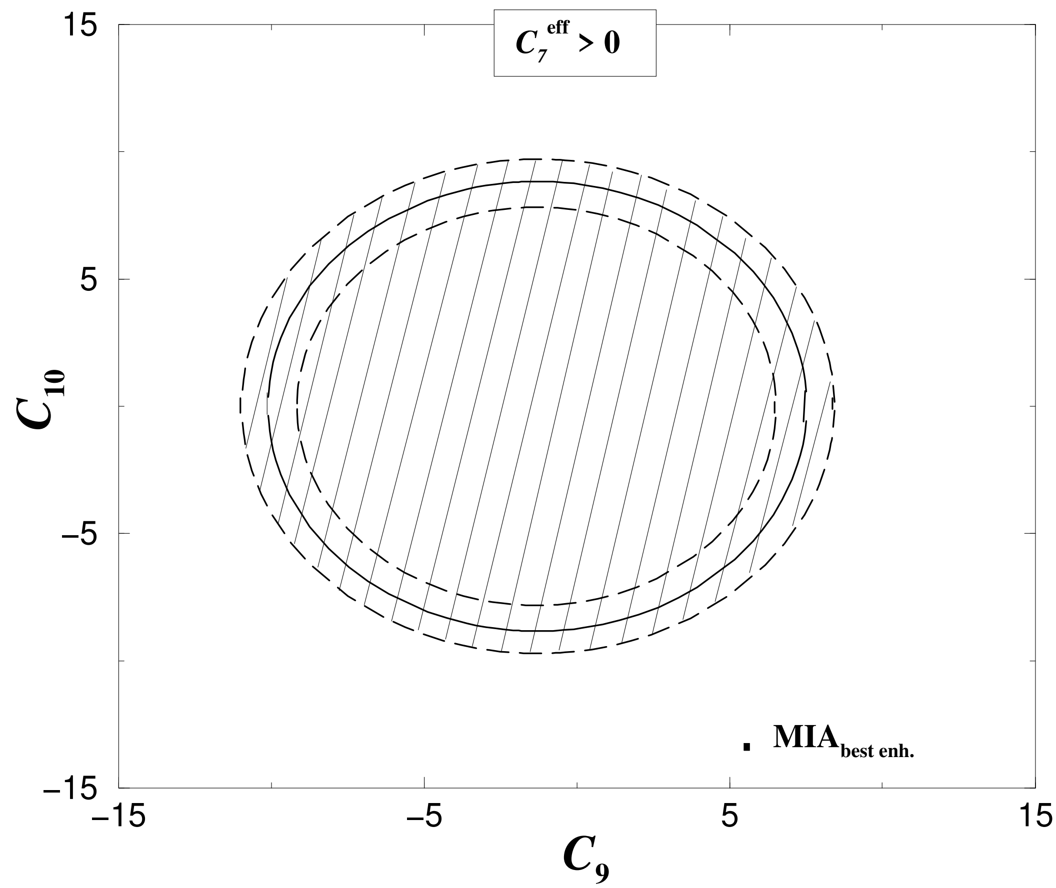
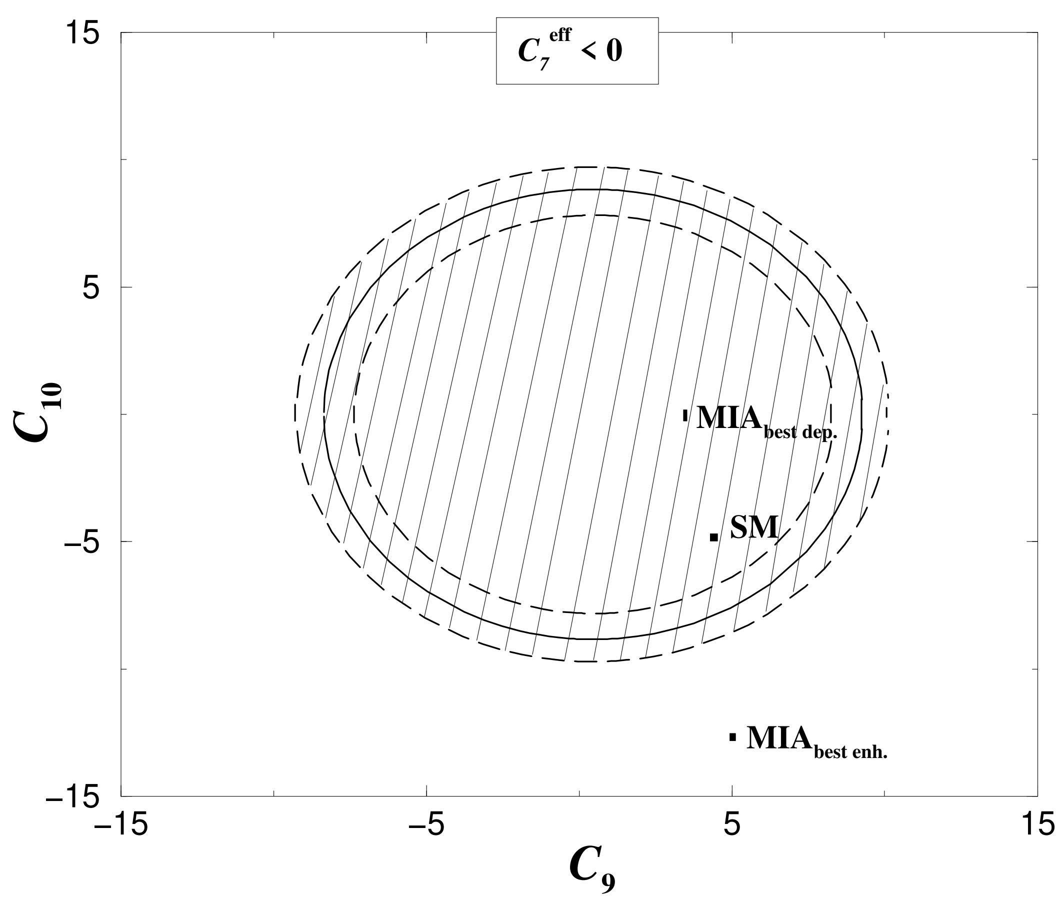


Figure 1: ABHH'99



Forward-Backward asymmetry

$q^2 = (p_+ + p_-)^2$

$$A_{FB}(q^2) = \frac{\int_0^1 \frac{\mathrm{d}\Gamma}{\mathrm{d}q^2 \mathrm{d}cos\theta} - \int_{-1}^0 \frac{\mathrm{d}\Gamma}{\mathrm{d}q^2 \mathrm{d}cos\theta}}{+}$$
$$\sim \alpha(q^2) Re(C_{10}^* \mathcal{C}_7{}^{\text{eff}}) + \beta(q^2) Re(C_{10}^* \mathcal{C}_9{}^{\text{eff}})$$

α, β: real functions of FF's
we are lucky: contribution of C'_{10} is suppressed by FF's

low q^2 region: SM: zero around 3GeV^2, whether zero or not tests the sign of $\mathcal{C}_7{}^{\text{eff}}$ ($\mathcal{C}_7{}^{\text{eff}}|_{SM} = -0.31$), important test of the SM and models beyond. e.g. in SUGRA only $\mathcal{C}_7{}^{\text{eff}} > 0$ for large $\tan\beta$, Goto et al

in 0.25GeV$^2 \leq q^2 < 8$GeV^2 for $\mathcal{C}_7{}^{\text{eff}} = +(-)\mathcal{C}_7{}^{\text{eff}}|_{SM}$:
$\Delta\mathcal{B}_{K^*} = 7.7(13.1) \cdot 10^{-7}$ and $\Delta\mathcal{A}'_{FB} = -9.2(-26.5)\%$

position of the zero: very small theoretical uncertainties from FF's
G.Burdman, ABHH'99 ratios involved: T_2/A_1, T_1/V

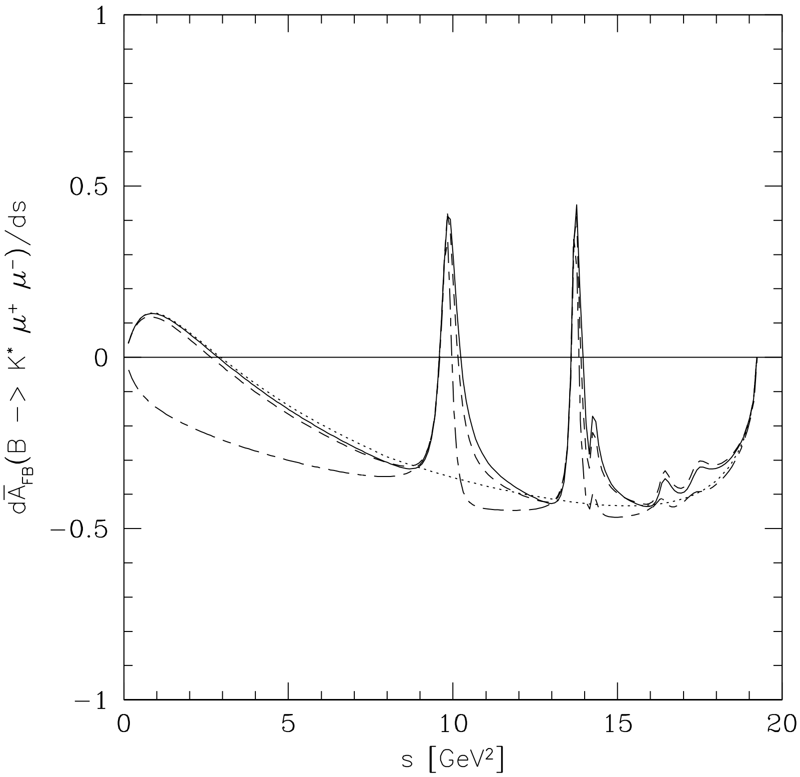


Figure 2: ABHH'99, solid: SM, short-long dashed: $C_7 = -C_7|_{SM}$

Proposal: testing the phase of $\bar{s}_L \gamma_\mu b_L Z^\mu (C_{10})$ with the FB-CP asymmetry

$$FB_{CP} = \frac{A_{FB} - \bar{A}_{FB}}{A_{FB} + \bar{A}_{FB}} = \tan\theta \frac{Im(\mathcal{C}_9{}^{\mathrm{eff}})}{Re(\mathcal{C}_9{}^{\mathrm{eff}})} [1 + \cdots]$$

$C_{10} = |C_{10}| \exp i\theta$, $\mathcal{C}_9{}^{\mathrm{eff}} = \mathcal{C}_9 + Y$, $Y(q^2)$: charm loop

- $FB_{CP} = 0$ for real C_{10}
- large effects for $\mathcal{O}(1)$ CP violating phases possible
- scales with $Im(\mathcal{C}_9{}^{\mathrm{eff}})$

high q^2 region $14.0\mathrm{GeV}^2 \leq q^2 < (m_B - m_{K^*})^2$

uncertainties: A) FF's: same ratios as for A_{FB} zero, $\leq 1\%$
B) SM background from up quark loops could fake C_{10} phases up to 1^0, $(b \to d$: $\theta_{eff} = -24^0)$

$$\tan\theta_{eff} \simeq \frac{Im(\lambda_t^* \lambda_u)}{|\lambda_t|^2} = \eta\lambda^2$$

$|\mathcal{FB}_{\mathcal{CP}}(\hat{s})|_{SM}| \leq 0.6\%$ in high q^2 region, integrated $\triangle\mathcal{FB}_{\mathcal{CP}}(\hat{s})|_{SM} = -6.2 \cdot 10^{-5}$

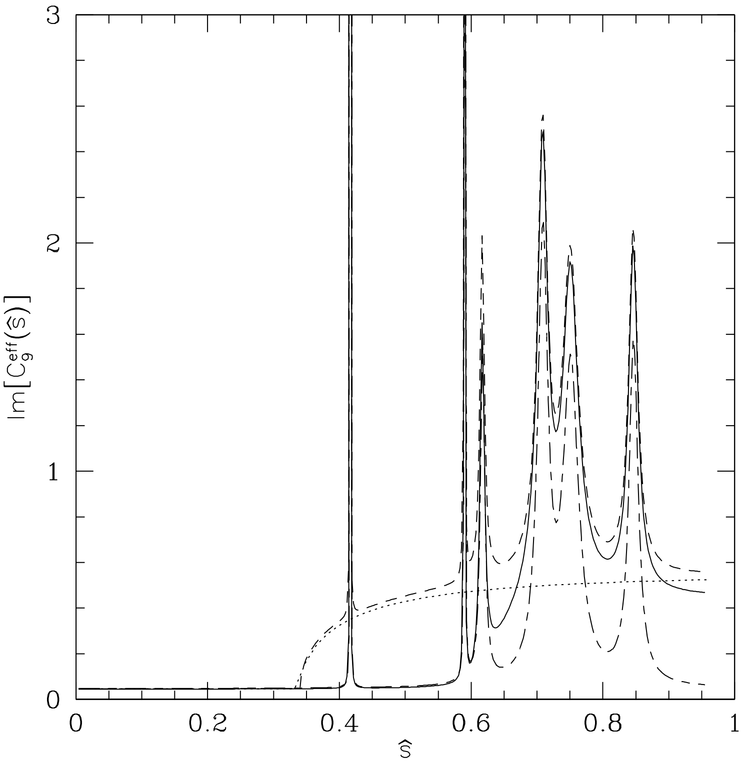


Figure 3: dotted: pure short distance, solid: long and short distance $c\bar{c}$ contributions via dispersion relation

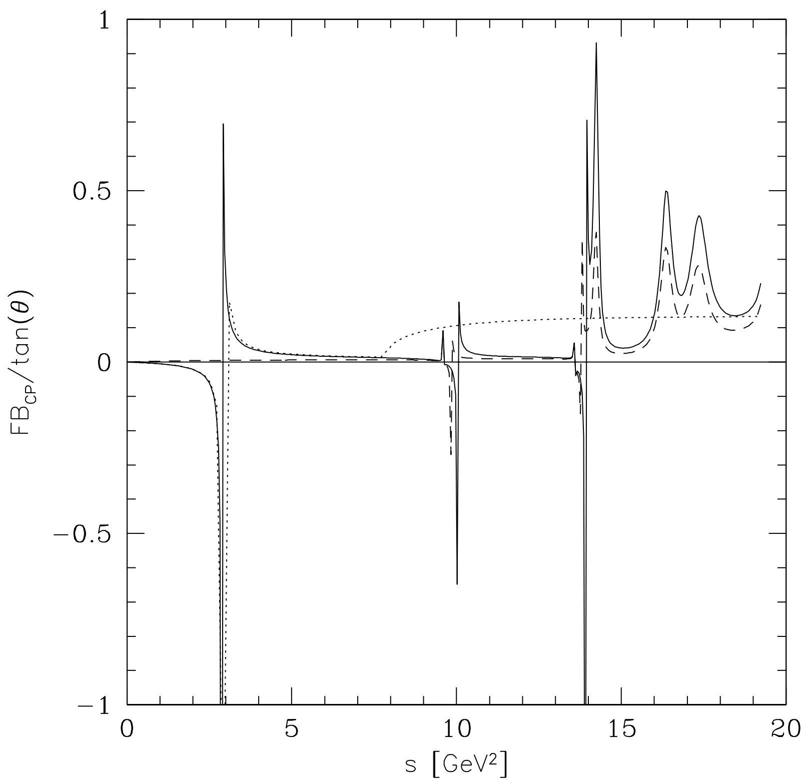


Figure 4: FB CP asymmetry in units of $\tan\theta$. dotted: pure short distance, solid (dashed): long and short distance $c\bar{c}$ contributions via dispersion relation and $C_7 = +(-)C_7|_{SM}$

C) from $\bar{c}c$ resonances, doesn't matter since the effect in the SM is so small !

	$\Delta\mathcal{B}_{K^*}$	$\Delta\langle\mathcal{A}_{FB}\rangle$	$\Delta\mathcal{A}'_{FB}$	$\Delta\mathcal{FB}_{\mathcal{CP}}/\tan\theta$
SM	$3.7\cdot 10^{-7}$	$-1.4\cdot 10^{-7}$	-36.7%	0
$-\mathcal{C}_7^{SM}$	$5.1\cdot 10^{-7}$	$-2.2\cdot 10^{-7}$	-42.0%	0
$+\mathcal{C}_7^{SM}$	$1.2\cdot 10^{-6}$	$+1.5\cdot 10^{-7}$	$+12.2\%$	$3.9\cdot 10^{-2}$
$-\mathcal{C}_7^{SM}$	$1.3\cdot 10^{-6}$	$+2.1\cdot 10^{-7}$	$+15.7\%$	$2.4\cdot 10^{-2}$

Table 1: *The last two rows correspond to* $|\mathcal{C}_{10}| = 10$ *and* $\theta = 3\pi/8$, $\Delta\mathcal{A}'_{FB} = \Delta\mathcal{A}_{FB}/\Delta\mathcal{B}_{K^*}$

we learn three things:

1) $B \to K^*\mu^+\mu^-$ branching ratio can be enhanced due to non-SM $|C_{10}|$
2) C_{10} phase can change the sign of the A_{FB}
3) non-zero phase induces $\Delta\mathcal{FB}_{CP} = 3.9\cdot 10^{-2}\tan\theta$

Statistical considerations:

example: $\Delta\mathcal{FB}_{CP} = 10\%$ $(\theta = 69^0)$ At 1σ for $\Delta\mathcal{A}'_{FB} = -40\%$, this amounts to ~ 300 events in high q^2 region

worthwhile to look for: in principle $\Delta\mathcal{FB}_{CP}$ can be much larger if $\theta \to \pi/2$

Summary

- Existing experimental bounds on the $B \to K^*\mu^+\mu^-$ branching ratio are already powerful enough to constrain the parameter space complementary to one by the $b \to s\gamma$ transition
- The Forward-Backward asymmetry A_{FB} is a very useful observable to test the SM and models beyond: whether or not there is a zero in the low q^2 region and as a second step programme where it exactly sits
- We propose a new observable to test features of a fundamental vertex $\bar{s}Zb$, the FB-CP asymmetry in $B \to K^*\mu^+\mu^-$ decays. Despite not small uncertainties related with higher Ψ' resonances, this is a no-loose game, since 1. the SM background due to CKM phases is very small and 2. the $\Delta\mathcal{FB}_{CP}$ can be sizeable in case of large CP violating phases
- It is a unique probe for flavor physics and worthwhile to be searched for