Angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$ at large recoil within the Aligned Two-Higgs-Doublet Model

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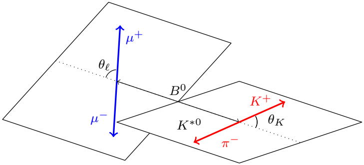
Content

1. Motivation

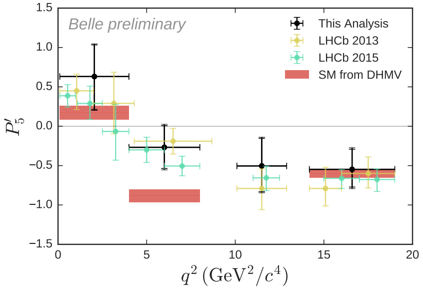
- P_5' **anomaly** $(> 3\sigma)$



"clean" observables at large recoil

$$P_5' = \frac{S_5}{2\sqrt{-S_2^s S_2^c}}, \quad P_2 = \frac{S_6^s}{8 S_2^s}$$

[S. Descotes-Genon, et al.: 1303.5794]



[Belle: 1604.04042]

2. The aligned two-Higgs doublet model (A2HDM)

In so-called "Higgs basis"

$$\Phi_1 = \begin{bmatrix} G^+ \\ \frac{1}{\sqrt{2}}\left(v + S_1 + iG^0\right) \end{bmatrix}, \qquad \Phi_2 = \begin{bmatrix} H^+ \\ \frac{1}{\sqrt{2}}\left(S_2 + iS_3\right) \end{bmatrix}.$$

Five physical degrees of freedom: two charged fields $H^{\pm}(x)$ and three neutral fields $\varphi_i^0(x) = \{h(x), H(x), A(x)\} = \mathcal{R}_{ij} S_j$.

The Yukawa Lagrangian

$$\mathcal{L}_Y = -\frac{\sqrt{2}}{v}\left[\bar{Q}'_L(M'_d\Phi_1+Y'_d\Phi_2)d'_R+\bar{Q}'_L(M'_u\tilde{\Phi}_1+Y'_u\tilde{\Phi}_2)u'_R+\bar{L}'_L(M'_\ell\Phi_1+Y'_\ell\Phi_2)\ell'_R\right]+$$

Aligned hypothesis [A. Pich and P. Tuzón: 0908.1554]

$$Y_{d,\ell} = \varsigma_{d,\ell}\, M_{d,\ell}\,, \qquad Y_u = \varsigma_u^*\, M_u\,,$$

Charged Higgs sector

$$\mathcal{L}_{H^\pm} = -\frac{\sqrt{2}}{v} H^+ \left\{ \bar{u} \left[\varsigma_d V_{\rm CKM} M_d P_R - \varsigma_u M_u^\dagger V_{\rm CKM} P_L \right] d + \varsigma_\ell \, \bar{\nu} M_\ell P_R \ell \right\} + \text{h.c.} \, ,$$

NFC models (based on discrete $\mathcal{Z}_2$ symmetries)

Model	$(\varsigma_d, \varsigma_u, \varsigma_\ell)$
Type I	$(\cot\beta, \cot\beta, \cot\beta)$
Type II	$(-\tan\beta, \cot\beta, -\tan\beta)$
Type X (lepton-specific)	$(\cot\beta, \cot\beta, -\tan\beta)$
Type Y (flipped)	$(-\tan\beta, \cot\beta, \cot\beta)$
Inert	(0,0,0)

3. Effective Hamiltonian

Effective Hamiltonian for $b \to s\mu^+\mu^-$ transitions

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i \left(C_i O_i + C_i' O_i' \right) ,$$

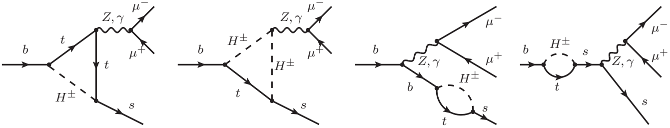
radiative and semileptonic operators

$$O_7 = \frac{e}{16\pi^2} \bar{m}_b \left(\bar{s} \sigma^{\mu\nu} P_R b \right) F_{\mu\nu} , \qquad O_7' = \frac{e}{16\pi^2} \bar{m}_b \left(\bar{s} \sigma^{\mu\nu} P_L b \right) F_{\mu\nu} ,$$

$$O_9 = \frac{e^2}{16\pi^2} \left(\bar{s} \gamma^\mu P_L b \right) \left(\bar{\mu} \gamma_\mu \mu \right) , \qquad O_9' = \frac{e^2}{16\pi^2} \left(\bar{s} \gamma^\mu P_R b \right) \left(\bar{\mu} \gamma_\mu \mu \right) ,$$

$$O_{10} = \frac{e^2}{16\pi^2} \left(\bar{s} \gamma^\mu R_L b \right) \left(\bar{\mu} \gamma_\mu \gamma_5 \mu \right) , \qquad O_{10}' = \frac{e^2}{16\pi^2} \left(\bar{s} \gamma^\mu P_R b \right) \left(\bar{\mu} \gamma_\mu \gamma_5 \mu \right) ,$$

Wilson coefficients in the A2HDM



Result

$$C_7^{\rm H^\pm} = |\varsigma_u|^2\, C_{7,\,\rm uu} + \varsigma_d \varsigma_u^* C_{7,\,\rm ud}\,,$$

$$C_9^{\rm H^\pm} = |\varsigma_u|^2\, C_{9,\,\rm uu}\,,$$

$$C_{10}^{\rm H^\pm} = |\varsigma_u|^2\, C_{10,\,\rm uu}\,,$$

$$C_7^{\prime \rm H^\pm} = \frac{m_s}{m_b}\left(|\varsigma_u|^2\, C_{7,\,\rm uu} + \varsigma_u \varsigma_d^* C_{7,\,\rm ud}\right)\,,$$

$$C_9^{\prime \rm H^\pm} = \left(-1 + 4\sin^2\theta_W\right) C_{10}^{\prime \rm H^\pm} + \frac{m_b m_s}{m_W^2}\left(|\varsigma_u|^2\, C'_{9,\,\rm uu} + 2\Re\left(\varsigma_u \varsigma_d^*\right) C'_{9,\,\rm ud} + |\varsigma_d|^2\, C'_{9,\,\rm dd}\right)\,,$$

$$C_{10}^{\prime \rm H^\pm} = \frac{m_b m_s}{m_W^2}\left(|\varsigma_u|^2\, C'_{10,\,\rm uu} + 2\Re\left(\varsigma_u \varsigma_d^*\right) C'_{10,\,\rm ud} + |\varsigma_d|^2\, C'_{10,\,\rm dd}\right).$$

4. Numerical results

(1) Restrict C_7^{NP}

the experimental combined result [Y. Amhis, et al.(HFAG) Collaboration: 1412.7515]

$$\mathcal{B}\left[b \to s\gamma\right]_{\mathrm{exp}} = (3.43 \pm 0.21 \pm 0.07) \times 10^{-4}.$$

The SM prediction at the NNLO in QCD is [M. Misiak, et al.: 1503.01789].

$$\mathcal{B}\left[b \to s\gamma\right]_{\mathrm{SM}} = (3.36 \pm 0.23) \times 10^{-4}.$$

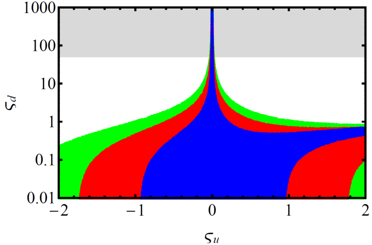
The $C_7^{\mathrm{H}^\pm}$ and $C_8^{\mathrm{H}^\pm}$ fulfill

$$-0.0634 \leq C_7^{\mathrm{H}^\pm} + 0.242\, C_8^{\mathrm{H}^\pm} \leq 0.0464\,.$$

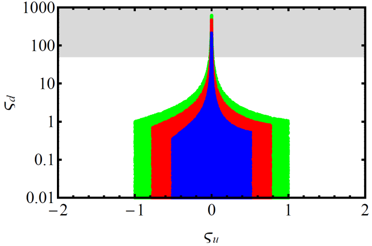
(2) Global fit results for NP contributions on Wilson coefficients $C_{9,10}^{(\prime)}$ [S. Descotes-Genon, et al.: 1510.04239; S. Meinel and D. van Dyk: 1603.02974]

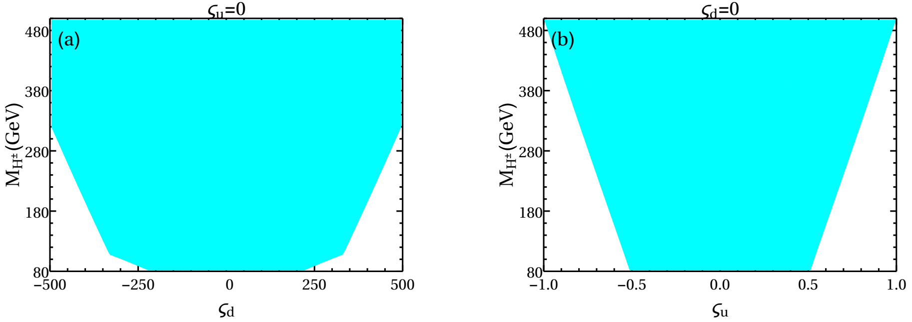
$$-2.2 \leq C_9^{\mathrm{NP}} \leq 2.5\,, \quad -0.5 \leq C_{10}^{\mathrm{NP}} \leq 4.2\,,$$
$$-1.3 \leq C_9^{\prime\mathrm{NP}} \leq 3.7\,, \quad -1.0 \leq C_{10}^{\prime\mathrm{NP}} \leq 3.1\,,$$

only (1)



(1) and (2)

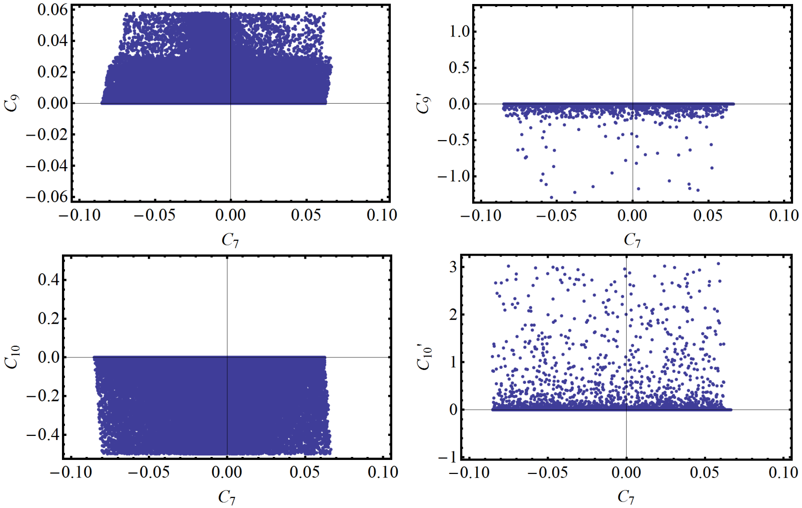


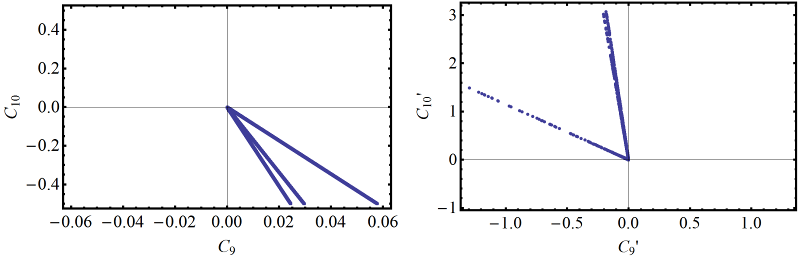


- $|\varsigma_d| \leq 212,\ 476,\ \text{and}\ 622;$
- $|\varsigma_u| \leq 0.506,\ 0.763,\ \text{and}\ 0.990;$

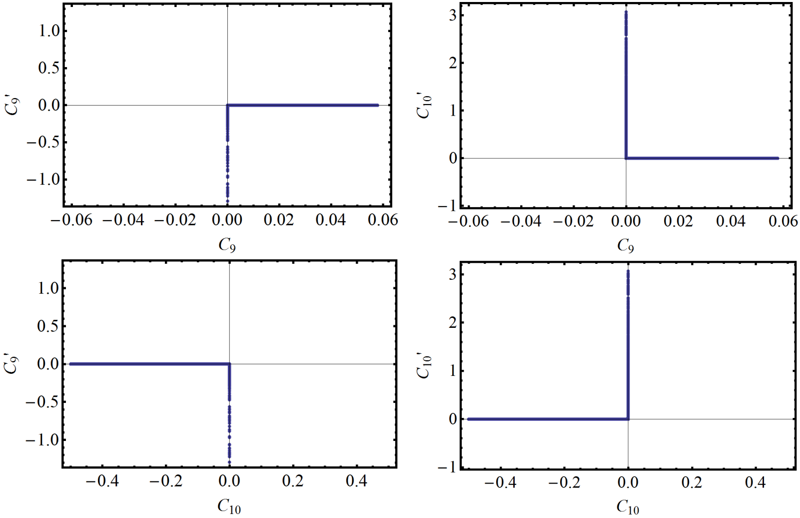
corresponding to $M_{H^\pm} = 80,\ 300,\ \text{and}\ 500\,\text{GeV}$, respectively.

The correlations between each Wilson coefficients are shown



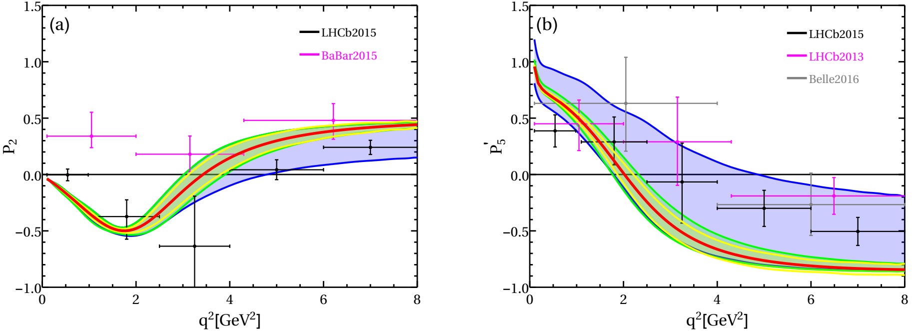


0.4
0.2
0.0
−0.2
−0.4
−0.06 −0.04 −0.02 0.00 0.02 0.04 0.06
C_9
C_{10}
3
2
1
0
−1
−1.0 −0.5 0.0 0.5 1.0
C_9'
C_{10}'



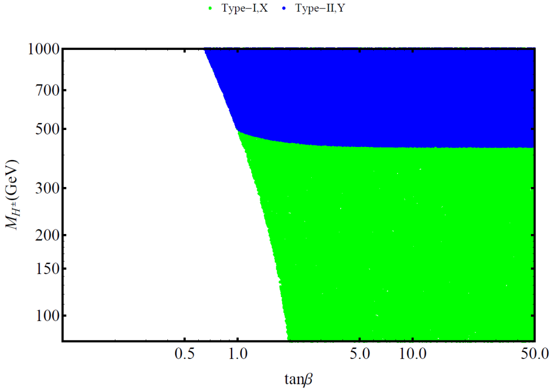
$$\text{case 1}: C_7^{H^\pm},\ C_9^{H^\pm},\ C_{10}^{H^\pm} \quad \text{with} \quad C_{9,10}^{\prime H^\pm} \simeq 0\,,$$

$$\text{case 2}: C_7^{H^\pm},\ C_9^{\prime H^\pm},\ C_{10}^{\prime H^\pm} \quad \text{with} \quad C_{9,10}^{H^\pm} \simeq 0\,.$$



	SM	A2HDM-case 1	A2HDM-case 2
$q_0^2(P_2)$	$3.43^{+0.33}_{-0.32}$	$(3.02,\ 3.90)$	$(3.02,\ 4.79)$
$q_0^2(P_5')$	$2.02^{+0.19}_{-0.15}$	$(1.77,\ 2.32)$	$(1.79,\ 4.85)$

Table: The zero-crossing points of P_2 (nonzero one) and P_5'.



$M_{H^\pm} \geq 432\,\text{GeV}$ in types-II,Y

5. Conclusions

- We presented a complete one-loop calculation of the $C_{7,9,10}^{(\prime)\mathrm{H}^\pm}$ in A2HDM.
- We obtain the allowed region in the $\varsigma_u - \varsigma_d$ plane. The constraints are $|\varsigma_u| \leq 0.506\,(0.990)$ and $|\varsigma_d| \leq 212\,(622)$ for $M_{H^\pm} = 80\,(500)$ GeV.
- In A2HDM, there are only two cases for Wilson coefficients of NP

$$\text{case 1}: C_7^{\mathrm{H}^\pm},\, C_9^{\mathrm{H}^\pm},\, C_{10}^{\mathrm{H}^\pm} \quad \text{with} \quad C_{9,10}^{\prime\mathrm{H}^\pm} \simeq 0\,,$$
$$\text{case 2}: C_7^{\mathrm{H}^\pm},\, C_9^{\prime\mathrm{H}^\pm},\, C_{10}^{\prime\mathrm{H}^\pm} \quad \text{with} \quad C_{9,10}^{\mathrm{H}^\pm} \simeq 0\,;$$

  There are only a small impact on P_2 and P_5' in case 1. The case 2 can supply a bigger P_5' than SM at large recoil (in low q^2), to conform with the experimental results.

- The charged-Higgs mass should be greater than 432 GeV in types-II,Y.

Thank You!