Erratum: A taste of dark matter: flavour constraints on pseudoscalar mediators

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A sign mistake has been found in the calculation of the flavour-changing amplitudes $b \rightarrow s A$ and $s \rightarrow d A$ in section 2.1 of [1]. As a result the vertex counter-term does not cancel the divergence of the one-loop diagram, so that the flavour-changing amplitudes $b \rightarrow s A$ and $s \rightarrow d A$ are in general divergent [2]. In dimensional regularisation we obtain a pole in $\epsilon = (4 - d)/2$ of the form

$$h_{sb}^R = \sum_{q=u,c,t} \frac{\alpha [3 m_s m_b m_q^2 g_s - (m_s^2 + 2 m_b^2) m_q^2 g_b + 2 m_b (m_s^2 - m_b^2) m_q g_q]}{16 \pi m_W^2 \sin(\theta_W)^2 (m_b^2 - m_s^2)} V_{qb} V_{qs}^* \times \frac{1}{\epsilon}, \quad (1)$$

where m_W is the W -boson mass, $\alpha \equiv e^2/(4\pi)$, θ_W is the Weinberg angle and V is the CKM matrix. The corresponding expression for h_{sb}^L (up to an overall sign) is obtained by exchanging s and b .

Interpreting our model as an effective theory below some new physics scale Λ corresponds to making the replacement $1/\epsilon + \log(\mu^2/m^2) \rightarrow \log(\Lambda^2/m^2)$, where $m = m_t$ is the

relevant mass scale for the process under consideration [3, 4]. We then obtain the following expressions in the limit $m_t \gg m_b \gg m_s$.¹

$$\text{Yukawa-like couplings:} \quad h_{sb}^R = -\frac{\alpha g_Y m_b m_t^2}{2\sqrt{2}\pi m_W^2 \sin(\theta_W)^2 v} V_{tb} V_{ts}^* \log\left(\frac{\Lambda^2}{m_t^2}\right), \quad (2)$$

$$\text{Universal couplings:} \quad h_{sb}^R = -\frac{\alpha g_q m_t^2}{8\pi m_W^2 \sin(\theta_W)^2} V_{tb} V_{ts}^* \log\left(\frac{\Lambda^2}{m_t^2}\right). \quad (3)$$

The corresponding expressions for h_{sb}^L (up to an overall sign) are again obtained by exchanging b and s . The results for h_{ds}^R and h_{ds}^L are completely analogous, except that in this case a second term with t replaced by c gives a relevant contribution. Using the full expression, substituting the measured masses, couplings and mixing angles, and taking $\Lambda = 1$ TeV, we find

$$\begin{aligned} h_{ds}^S &\approx (3.5 \cdot 10^{-9} + 1.5 \cdot 10^{-9}i) g_Y, & h_{ds}^P &\approx (3.9 \cdot 10^{-9} + 1.7 \cdot 10^{-9}i) g_Y, \\ h_{sb}^S &\approx (2.3 \cdot 10^{-5} - 4.2 \cdot 10^{-7}i) g_Y, & h_{sb}^P &\approx (2.3 \cdot 10^{-5} - 4.4 \cdot 10^{-7}i) g_Y. \end{aligned} \quad (4)$$

for Yukawa-like couplings,

$$\begin{aligned} h_{ds}^S &\approx (4.6 \cdot 10^{-6} + 2.0 \cdot 10^{-6}i) g_q, & h_{ds}^P &\approx (1.7 \cdot 10^{-6} + 7.3 \cdot 10^{-7}i) g_q, \\ h_{sb}^S &\approx (6.3 \cdot 10^{-4} - 1.2 \cdot 10^{-5}i) g_q, & h_{sb}^P &\approx (6.9 \cdot 10^{-4} - 1.3 \cdot 10^{-5}i) g_q, \end{aligned} \quad (5)$$

for quark-universal couplings, and

$$\begin{aligned} h_{ds}^S &\approx (1.7 \cdot 10^{-9} + 7.6 \cdot 10^{-10}i) g_Q, & h_{ds}^P &\approx (1.9 \cdot 10^{-9} + 8.4 \cdot 10^{-10}i) g_Q, \\ h_{sb}^S &\approx (4.3 \cdot 10^{-4} - 8.0 \cdot 10^{-6}i) g_Q, & h_{sb}^P &\approx (4.5 \cdot 10^{-4} - 8.5 \cdot 10^{-6}i) g_Q, \end{aligned} \quad (6)$$

for couplings only to the third generation.

As a result, we find stronger constraints for the case of Yukawa-like couplings compared to the ones obtained in [1]. The corrected constraints are shown in figure 1. In particular, we obtain a highly relevant bound from $B_s \rightarrow \mu^+ \mu^-$, which implies

$$g_Y \lesssim 0.9 \left(\frac{m_A}{10 \text{ GeV}} \right) \quad (7)$$

for $m_A \gg m_{B_s}$. As a result, an interpretation of the Galactic Centre Excess in terms of a pseudoscalar mediator with Yukawa-like couplings is excluded for $m_A \lesssim 10$ GeV, rather than for $m_A \lesssim 5$ GeV. Apart from this correction, our conclusions remain unchanged.

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¹We note that our result for Yukawa-like couplings differs by a factor of 4 from the one obtained for a pseudoscalar with derivative coupling of the form $\partial^\mu a \bar{f} \gamma_\mu \gamma^5 f$ [3]. The reason is that these two interactions are not equivalent at the one-loop level unless one also includes additional dimension-5 operators involving a pseudoscalar and a Higgs boson. We have checked that, when including these additional interactions, we reproduce the results from [3].

Figure 1. Corrected constraints for the case of Yukawa-like couplings. The left (right) panel corresponds to the left panel in figure 3 (top-left panel in figure 11) of [1].

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References

- [1] M.J. Dolan, C. McCabe, F. Kahlhoefer and K. Schmidt-Hoberg, *A taste of dark matter: flavour constraints on pseudoscalar mediators*, *JHEP* **03** (2015) 171 [[arXiv:1412.5174](https://arxiv.org/abs/1412.5174)] [[INSPIRE](https://inspirehep.net/literature/1254441)].
- [2] M. Freytsis, Z. Ligeti and J. Thaler, *Constraining the axion portal with $B \rightarrow K \ell^+ \ell^-$* , *Phys. Rev. D* **81** (2010) 034001 [[arXiv:0911.5355](https://arxiv.org/abs/0911.5355)] [[INSPIRE](https://inspirehep.net/literature/824441)].
- [3] B. Batell, M. Pospelov and A. Ritz, *Multi-lepton signatures of a hidden sector in rare B decays*, *Phys. Rev. D* **83** (2011) 054005 [[arXiv:0911.4938](https://arxiv.org/abs/0911.4938)] [[INSPIRE](https://inspirehep.net/literature/824441)].
- [4] R. Essig, R. Harnik, J. Kaplan and N. Toro, *Discovering new light states at neutrino experiments*, *Phys. Rev. D* **82** (2010) 113008 [[arXiv:1008.0636](https://arxiv.org/abs/1008.0636)] [[INSPIRE](https://inspirehep.net/literature/878441)].