A minimal axion model for mass matrices with five texture-zeros

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The five texture-zero mass matrices:

$$M^U = \begin{pmatrix} 0 & 0 & |C_u|e^{i\phi_{C_u}} \\ 0 & A_u & |B_u|e^{i\phi_{B_u}} \\ |C_u|e^{-i\phi_{C_u}} & |B_u|e^{-i\phi_{B_u}} & D_u \end{pmatrix},$$

$$M^D = \begin{pmatrix} 0 & |C_d| & 0 \\ |C_d| & 0 & |B_d| \\ 0 & |B_d| & A_d \end{pmatrix}, \qquad (1)$$

$$M^N = \begin{pmatrix} 0 & |C_\nu|e^{ic_\nu} & 0 \\ |C_\nu|e^{-ic_\nu} & E_\nu & |B_\nu|e^{ib_\nu} \\ 0 & |B_\nu|e^{-ib_\nu} & A_\nu \end{pmatrix}$$

$$M^E = \begin{pmatrix} 0 & |C_\ell| & 0 \\ |C_\ell| & 0 & |B_\ell| \\ 0 & |B_\ell| & A_\ell \end{pmatrix}, \qquad (2)$$

We are shown that the analyzed texture (1) needs at least four Higgs doublets, to reproduce the five-texture zeros with the PQ symmetry.

The same Higgs doublets reproduce satisfactorily (2) .

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PQ symmetry and the minimal particle content

Particles	Spin	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$	$Q_{\mathrm{PQ}}(i=1)$	$Q_{\mathrm{PQ}}(i=2)$	$Q_{\mathrm{PQ}}(i=3)$	$U(1)_{\mathrm{PQ}}$
q_{Li}	1/2	3	2	1/6	$-2s_1+2s_2+\alpha$	$-s_1+s_2+\alpha$	α	x_{q_i}
u_{Ri}	1/2	3	1	2/3	$s_1+\alpha$	$s_2+\alpha$	$-s_1+2s_2+\alpha$	x_{u_i}
d_{Ri}	1/2	3	1	$-1/3$	$2s_1-3s_2+\alpha$	$s_1-2s_2+\alpha$	$-s_2+\alpha$	x_{d_i}
ℓ_{Li}	1/2	1	2	$-1/2$	$-2s_1+2s_2+\alpha'$	$-s_1+s_2+\alpha'$	α'	x_{ℓ_i}
e_{Ri}	1/2	1	1	-1	$2s_1-3s_2+\alpha'$	$s_1-2s_2+\alpha'$	$-s_2+\alpha'$	x_{e_i}
ν_{Ri}	1/2	1	1	0	$-4s_1+5s_2+\alpha'$	$-s_1+2s_2+\alpha'$	$s_2+\alpha'$	x_{ν_i}

Particles	Spin	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$	Q_{PQ}	$U(1)_{\mathrm{PQ}}$
ϕ_1	0	1	2	1/2	s_1	x_{ϕ_1}
ϕ_2	0	1	2	1/2	s_2	x_{ϕ_2}
ϕ_3	0	1	2	1/2	$-s_1+2s_2$	x_{ϕ_3}
ϕ_4	0	1	2	1/2	$-3s_1+4s_2$	x_{ϕ_4}
S	0	1	1	0	$x_S=s_1-s_2\neq 0$	x_S
Q_L	1/2	3	1	0	$x_{Q_L}-x_{Q_R}\neq 0$	x_{Q_L}
Q_R	1/2	3	1	0		x_{Q_R}

$$Q_{PQ}(s_1,N,\alpha)(\psi)=\frac{N}{9}\left(\hat{s}_1 Q^{s_1}_{PQ}(\psi)+(\epsilon+\hat{s}_1)Q^{s_2}_{PQ}(\psi)\right)+\alpha Q^{V_q}_{PQ}(\psi)+\alpha' Q^{V_l}_{PQ}(\psi),$$

with $\epsilon=(1-A_Q/N)$ and $A_Q=x_{Q_L}-x_{Q_R}$

$\epsilon\neq 0.$

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Naturalness of Yukawa couplings

$$M^D = \begin{pmatrix} 0 & |y_{12}^{D4}|\hat{v}_4 & 0 \\ |y_{12}^{D4}|\hat{v}_4 & 0 & |y_{23}^{D3}|\hat{v}_3 \\ 0 & |y_{23}^{D3}|\hat{v}_3 & y_{33}^{D2}\hat{v}_2 \end{pmatrix} \qquad M^U = \begin{pmatrix} 0 & 0 & y_{13}^{U1}\hat{v}_1 \\ 0 & y_{22}^{U1}\hat{v}_1 & y_{23}^{U2}\hat{v}_2 \\ y_{13}^{U1^*}\hat{v}_1 & y_{23}^{U2^*}\hat{v}_2 & y_{33}^{U3}\hat{v}_3 \end{pmatrix}$$

$$\hat{v}_i = v_i/\sqrt{2}$$

By setting various Yukawa couplings close to 1 in the quarks sector (except y_{23}^{U2}, y_{23}^{D3} and y_{13}^{U1}) we obtain:

$$\hat{v}_1 = 1.71\,\mathrm{GeV}, \qquad \hat{v}_2 = 2.91\,\mathrm{GeV}, \qquad \hat{v}_3 = 174.085\,\mathrm{GeV}, \qquad \hat{v}_4 = 13.3\,\mathrm{MeV}.$$

$$(v_1^2 + v_2^2 + v_3^2 + v_4^2) = (246.24\,\mathrm{GeV})^2$$

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Mass spectrum for the scalar sector:

The mass spectrum of the scalar fields is above the TeVs scale, except the SM Higgs which was set to 125 GeV. The pseudoscalar sector (CP odd fields) have two zero mass eigenstates, the axion field and the Goldstone boson which is absorbed by the longitudinal component of the MZ boson. A similar result is achieved in the charged sector where it is possible to identify the two Goldstone bosons needed to give mass to the SM $W^{\pm}$ fields.

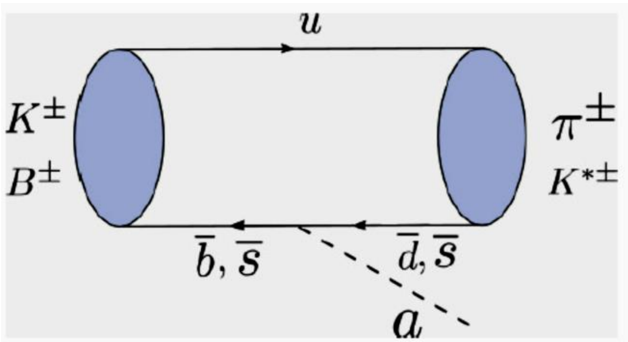
$$f_a = \frac{v_S}{2N}, \qquad v_S \approx 10^6 \mathrm{GeV}.$$

$$\mathrm{CP\ even} = \{1.41 \times 10^6, 6.54 \times 10^3, 1.97 \times 10^3, 1.09 \times 10^3, 125\}, \mathrm{GeV}$$

$$\mathrm{CP\ odd} = \{6.54 \times 10^3, 1.97 \times 10^3, 1.09 \times 10^3, 0, 0\}, \mathrm{GeV}$$

$$\mathrm{Charged\ fields} = \{6.54 \times 10^3, 1.97 \times 10^3, 1.11 \times 10^3, 0\}. \ \mathrm{GeV}$$

LOW ENERGY CONSTRAINTS

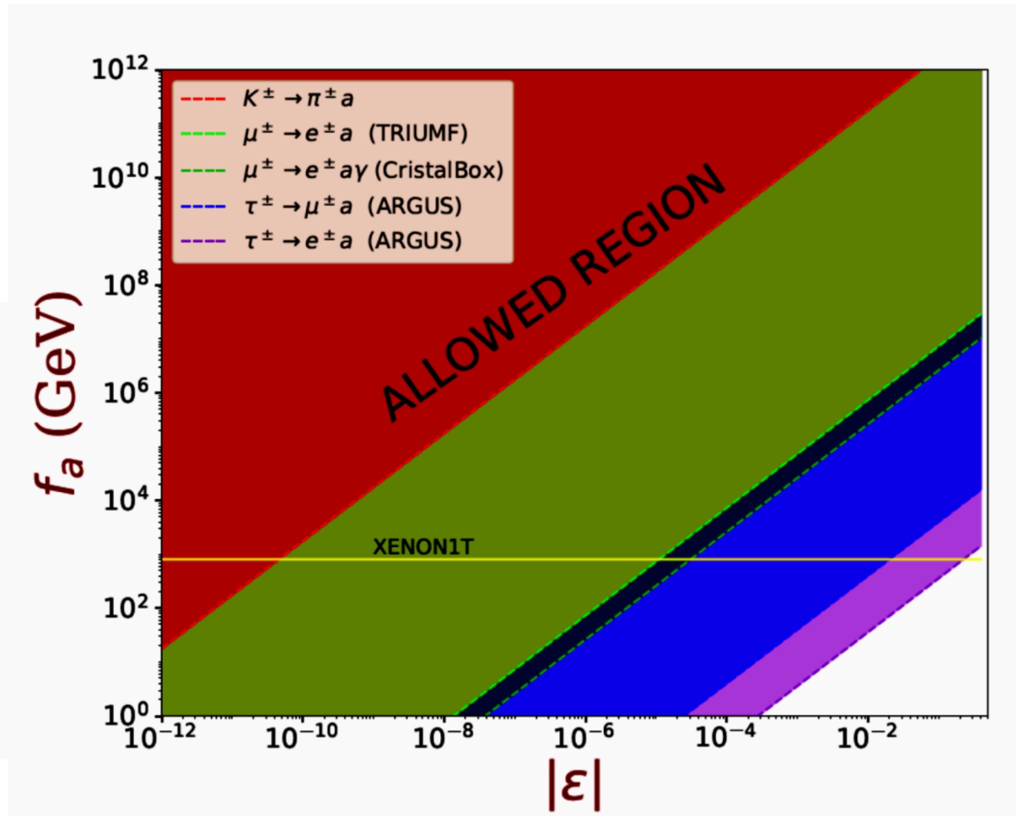


$$\Gamma(K^\pm \to \pi^\pm a) = \frac{m_K^3}{16\pi}\left(1 - \frac{m_\pi^2}{m_K^2}\right)^2 \lambda_{K\pi a}^{1/2} f_0^2(m_a^2)|g_{ads}^V|^2.$$

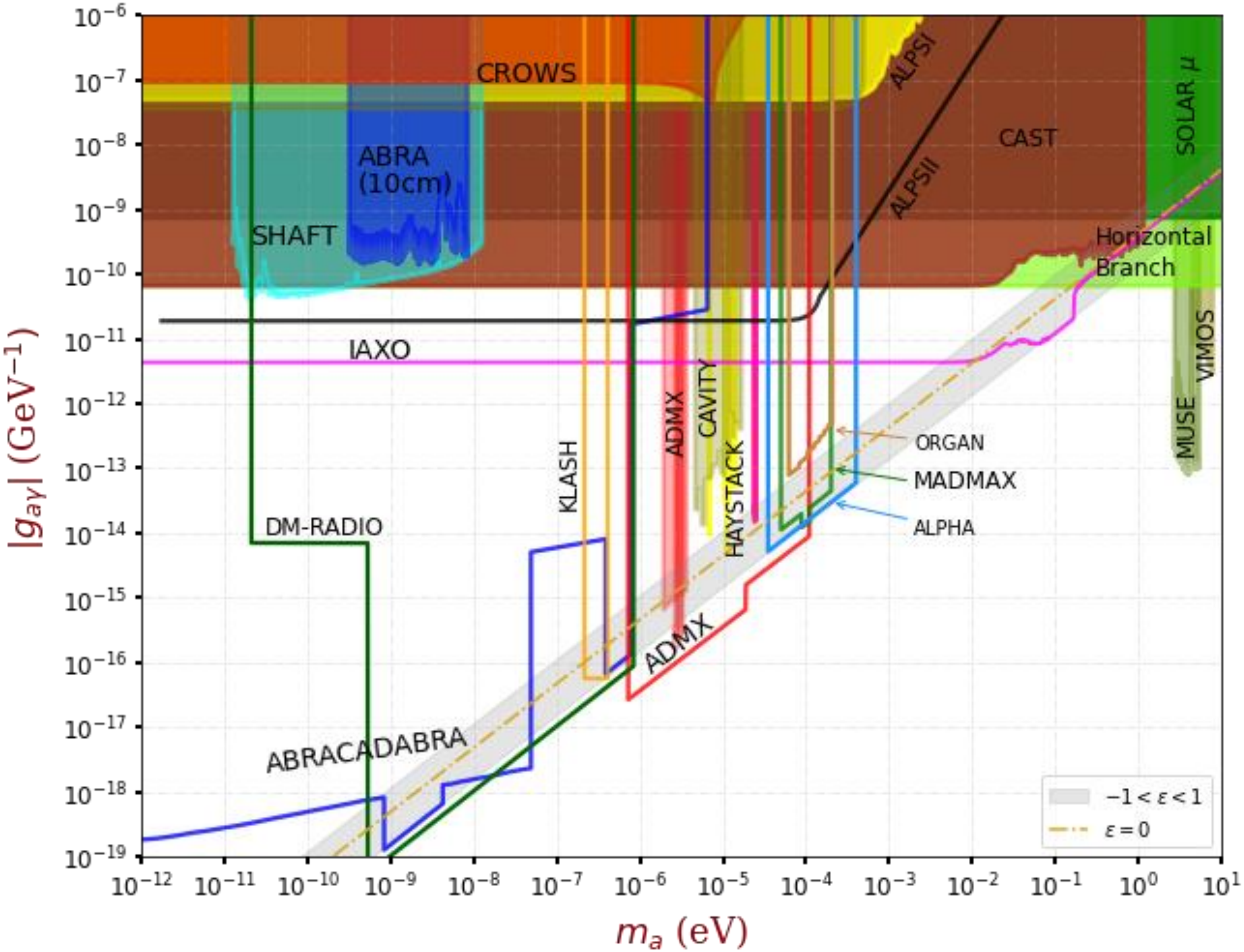
$$\Gamma(B \to K^* a) = \frac{m_B^3}{16\pi}\lambda_{BK^*a}^{3/2} A_0^2(m_a^2)|g_{asb}^A|^2.$$

$$g_{ad_id_j}^{V,A} = \frac{1}{2 f_a c_3^{\text{eff}}}\Delta_{V,A}^{Dij},$$

Collaboration	Upper bound
E949+E787 [148,149]	$\mathcal{B}(K^+ \to \pi^+ a) < 0.73 \times 10^{-10}$
CLEO [150]	$\mathcal{B}(B^\pm \to \pi^\pm a) < 4.9 \times 10^{-5}$
CLEO [150]	$\mathcal{B}(B^\pm \to K^\pm a) < 4.9 \times 10^{-5}$
BELLE [151]	$\mathcal{B}(B^\pm \to \rho^\pm a) < 21.3 \times 10^{-5}$
BELLE [151]	$\mathcal{B}(B^\pm \to K^{*\pm} a) < 4.0 \times 10^{-5}$



CONSTRAINTS ON THE AXION-PHOTON COUPLING



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