FLASY 2025

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Flavored Peccei-Quinn symmetries in the minimal νDFSZ model

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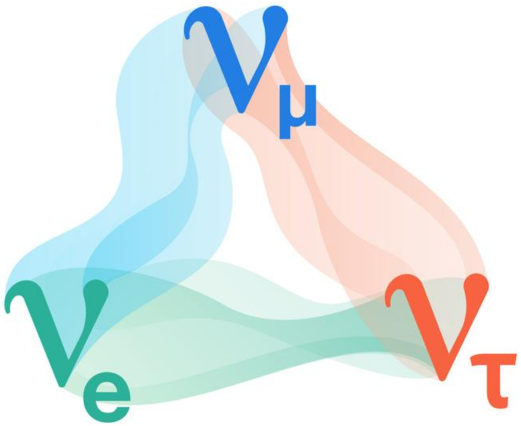
In collaboration with: H. B. Câmara and F. R. Joaquim

arXiv: 2504.00088 [hep-ph]

Neutrino Oscillations



Introduction

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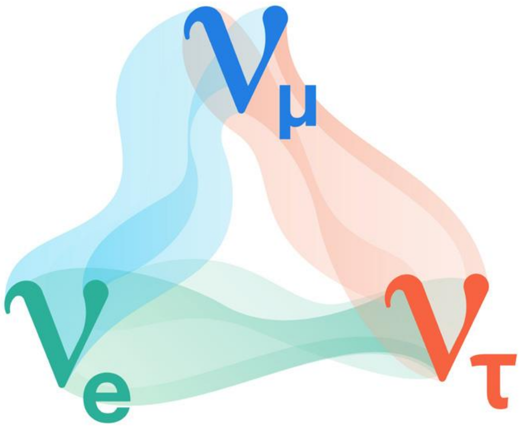
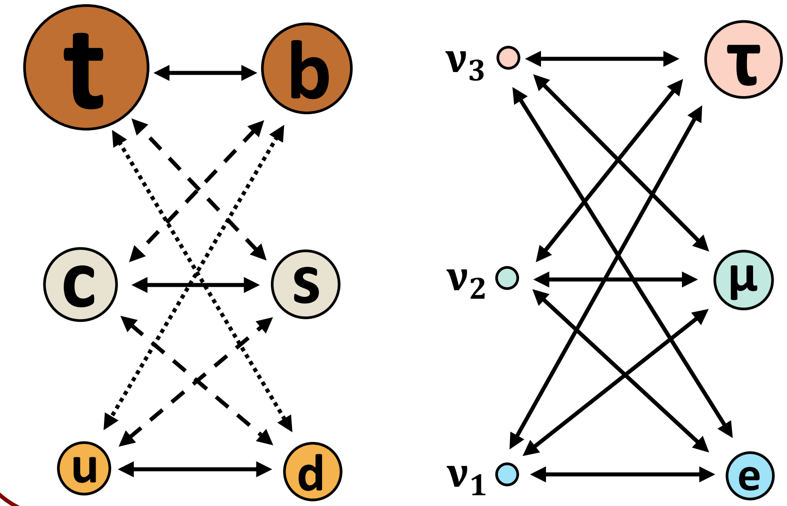


Flavour Puzzle



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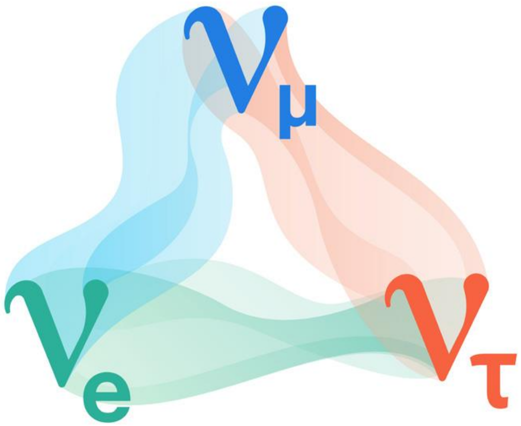

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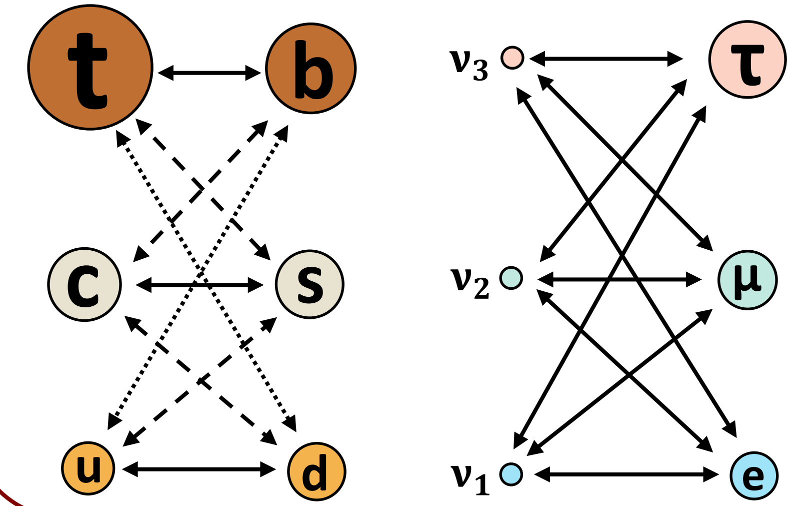

Strong CP Problem

$$\mathcal{L}_{\rm QCD} \supset \bar{\theta}\frac{g_s^2}{32\pi^2}G^a_{\mu\nu}\tilde{G}^{\mu\nu}_a$$

$$|\bar{\theta}| < 10^{-10}$$

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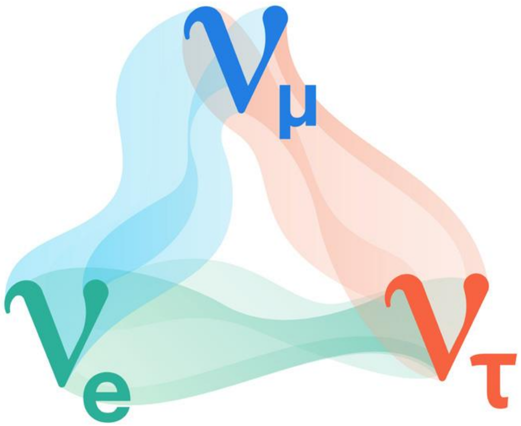

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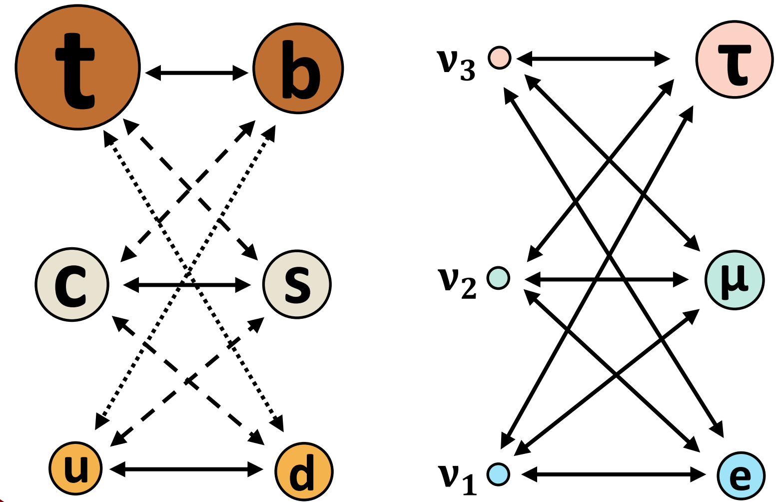

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Dark Matter

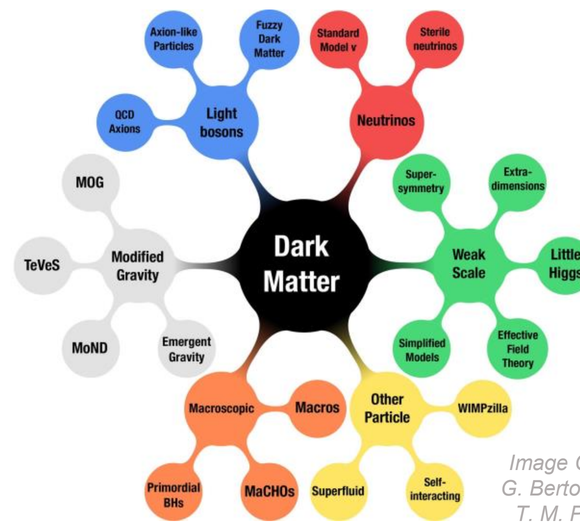

Image Credit: G. Bertone and T. M. P. Tait

Minimal Type-I Seesaw Mechanism

$$\mathcal{L}_{\rm I} = \mathcal{L}_{\rm SM} + i\overline{\nu_R}\gamma^\mu \partial_\mu \nu_R - \left(\overline{\ell_L} \mathbf{Y}_\nu^* \widetilde{\Phi} \nu_R + \frac{1}{2} \overline{\nu_R} \mathbf{M}_R \nu_R^c + \ \text{H.c.} \ \right)$$

Neutrino Masses and Mixing

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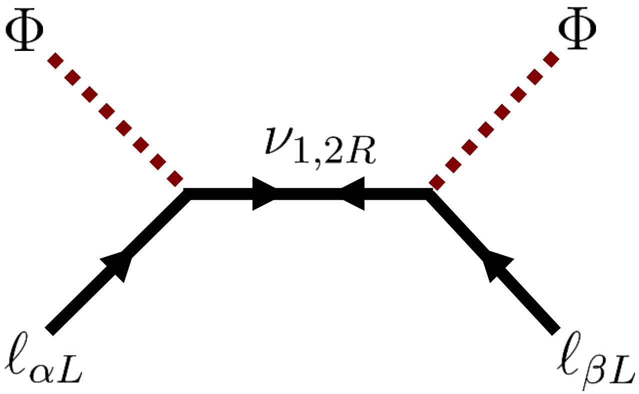

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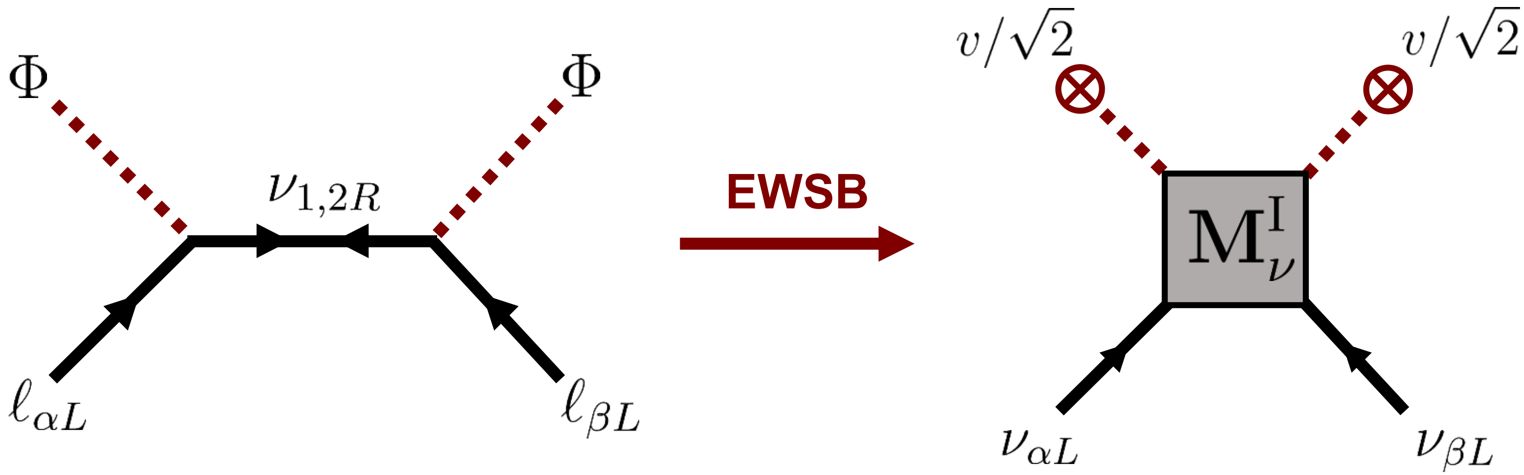

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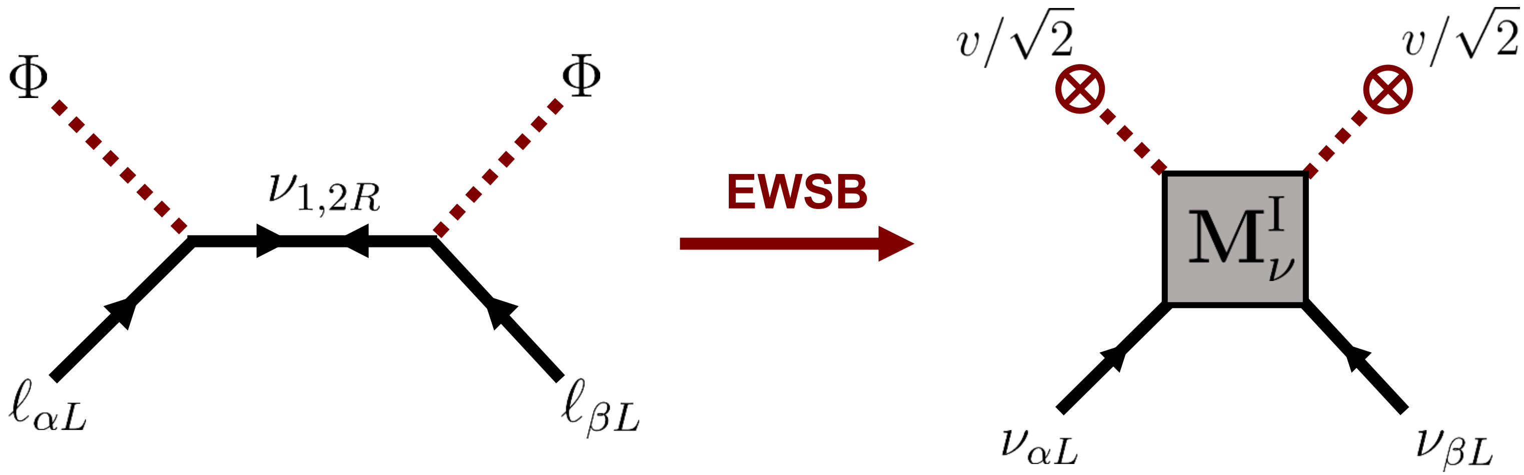

Majorana Mass Eigenstates

$$\mathbf{M}_\nu^{\mathrm{I}} = -\frac{v^2}{2}\mathbf{Y}_\nu\mathbf{M}_R^{-1}\mathbf{Y}_\nu^T$$

$$\mathbf{U}_L^{\nu T}\mathbf{M}_\nu^{\mathrm{I}}\mathbf{U}_L^\nu = \mathrm{diag}\left(m_1, m_2, m_3\right)$$

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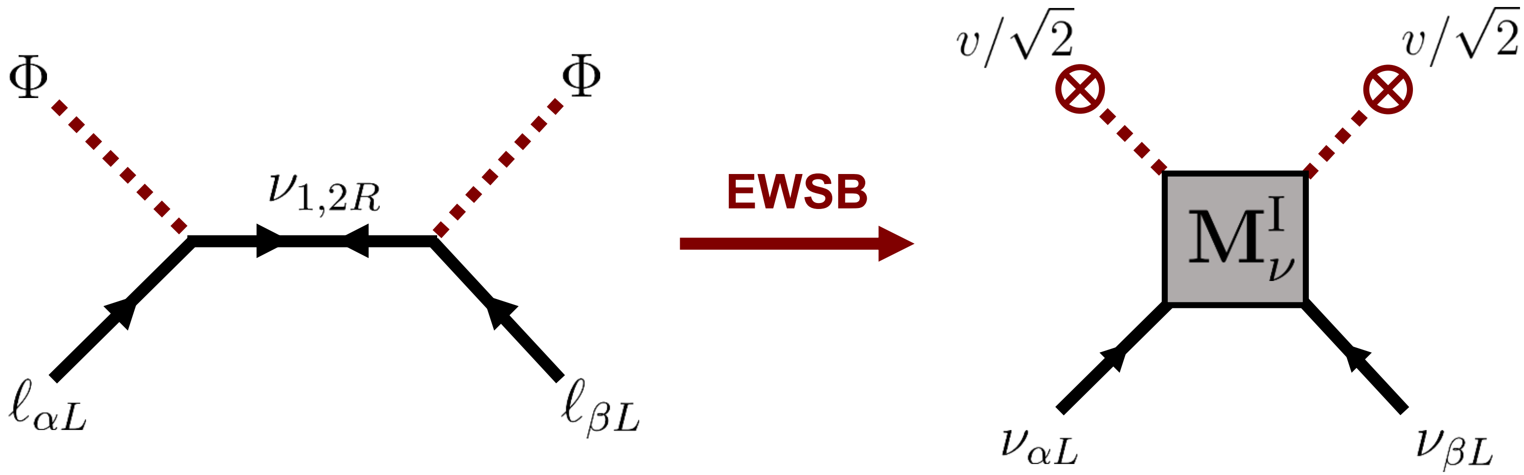

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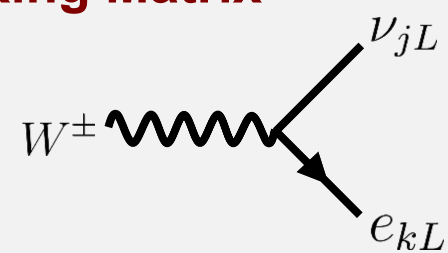
Lepton Mixing Matrix

$$\mathbf{U}_\ell = \mathbf{U}_L^{e\dagger}\mathbf{U}_L^\nu$$



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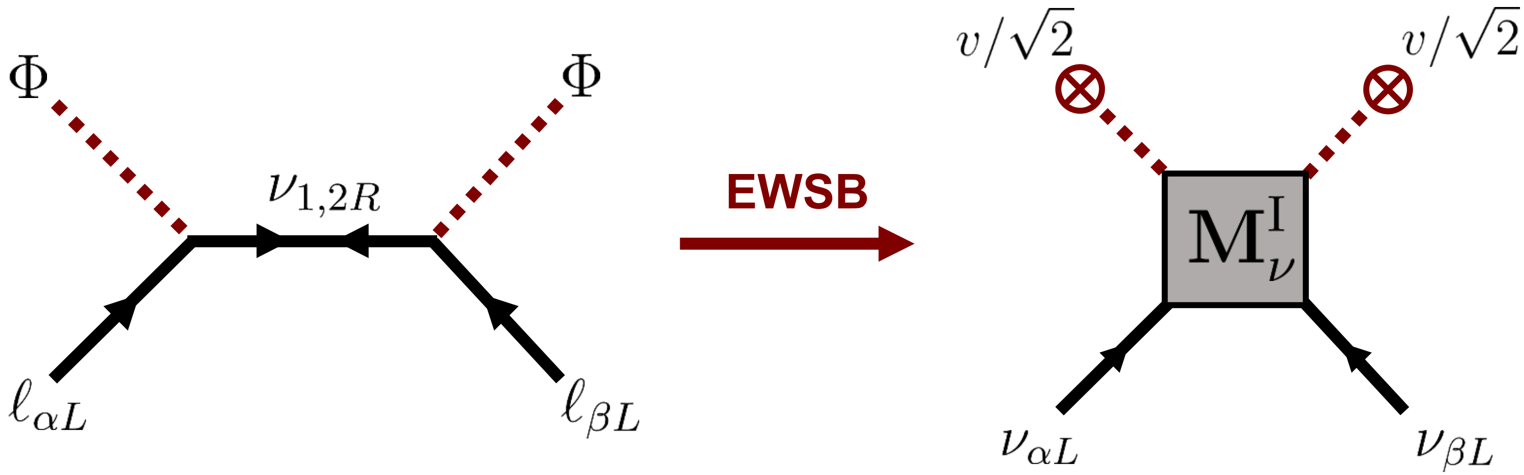

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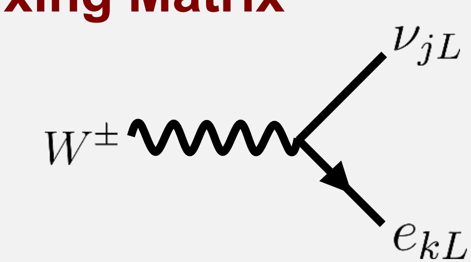

The lightest neutrino is predicted to be massless!

Peccei-Quinn Mechanism

Global $U(1)_{PQ}$

$$\Phi_k \to \exp\left(i\zeta\chi_k\right)\Phi_k\ ,\quad q_{L_\alpha} \to \exp\left(i\zeta\chi^L_{q_\alpha}\right) q_{L\alpha}\ ,\quad d_{R_\alpha} \to \exp\left(i\zeta\chi^R_{d_\alpha}\right) d_{R\alpha}\ ,\quad u_{R\alpha} \to \exp\left(i\zeta\chi^R_{u_\alpha}\right) u_{R\alpha}$$

$$\sigma \to \exp\left(i\zeta\chi_\sigma\right)\sigma\ ,\qquad \ell_{L\alpha} \to \exp\left(i\zeta\chi^L_{\ell_\alpha}\right)\ell_{L\alpha}\ ,\quad e_{R\alpha} \to \exp\left(i\zeta\chi^R_{e_\alpha}\right) e_{R\alpha}\ ,\quad \nu_{Rj} \to \exp\left(i\zeta\chi^R_{\nu_j}\right)\nu_{Rj}$$

2HDM

$$\Phi_{1,2} = \frac{1}{\sqrt{2}}\begin{pmatrix} \phi^+_{1,2} \\ \left(v_{1,2} + \rho_{1,2}\right) e^{ia_{1,2}/v_{1,2}} \end{pmatrix}$$

Complex Singlet

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Mass Basis →

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In the Low energy effective theory

$$\langle a \rangle_{k=0,1,\ldots,N_{\mathrm{DW}}-1} = (-\bar{\theta} + 2\pi k)v_a/N_{\mathrm{DW}}$$

$$m_a = 5.70(7)\left(\frac{10^{12}\mathrm{GeV}}{f_a}\right)\mu\mathrm{eV}$$

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The Strong CP Problem is solved

Axion Dark Matter and Cosmology

Axions are **naturally light**, **weakly coupled** with ordinary matter, cosmologically **stable**, and can be **nonthermally produced in the early Universe** being an **excellent DM candidate**

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Cosmological Scenarios for Axion Production

Axion dark matter via the **misalignment mechanism in the pre-inflationary scenario**

$$\Omega_a h^2 \simeq \Omega_{\mathrm{CDM}} h^2 \frac{\theta_0^2}{2.15^2} \left(\frac{f_a}{2 \times 10^{11} \mathrm{GeV}} \right)^{\frac{7}{6}}$$

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Topological Defects

Axion Strings   Domain Walls

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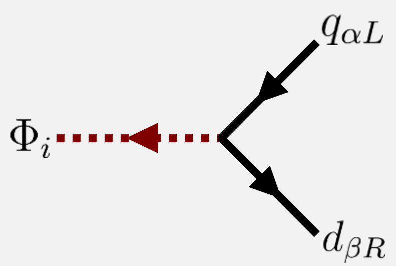
Topological Defects

Axion Strings ~~Domain Walls~~

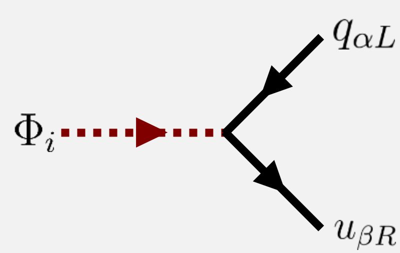
$N_{\mathrm{DW}} = 1$

$$-\mathcal{L}_{\text{mass}} = \overline{d_L}\mathbf{M}_d d_R + \overline{u_L}\mathbf{M}_u u_R + \overline{e_L}\mathbf{M}_e e_R + \overline{\nu_L}\mathbf{M}_D^* \nu_R + \frac{1}{2}\overline{\nu_R}\mathbf{M}_R \nu_R^c + \text{H.c.}$$

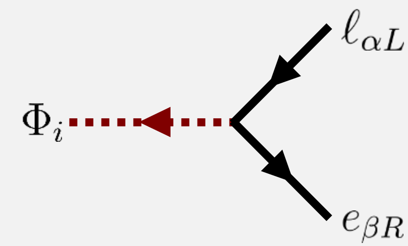
$$\mathbf{M}_d \sim \begin{pmatrix} \times & \times & \times \\ \times & \times & \times \\ \times & \times & \times \end{pmatrix}$$



$$\mathbf{M}_u \sim \begin{pmatrix} \times & \times & \times \\ \times & \times & \times \\ \times & \times & \times \end{pmatrix}$$



$$\mathbf{M}_e \sim \begin{pmatrix} \times & \times & \times \\ \times & \times & \times \\ \times & \times & \times \end{pmatrix}$$



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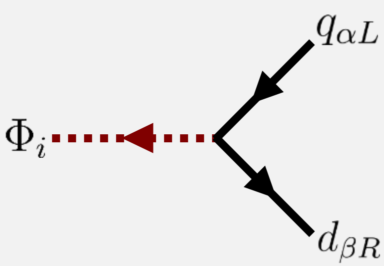
$$\mathbf{M}_d \sim \begin{pmatrix} 0 & 0 & \boxtimes \\ 0 & \boxtimes & 0 \\ \boxtimes & 0 & \boxtimes \end{pmatrix}$$



$i = 1, 2, 1, 2$
$\alpha = 1, 2, 3, 3$
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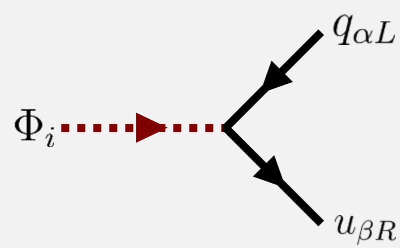

$i = 2, 1, 1, 2, 1$
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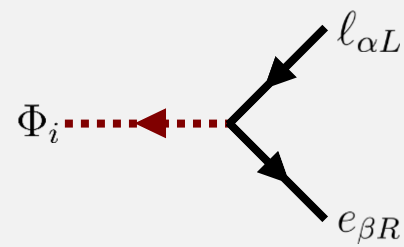
$$\mathbf{M}_e \sim \begin{pmatrix} 0 & 0 & \boxtimes \\ 0 & \boxtimes & 0 \\ \boxtimes & 0 & \boxtimes \end{pmatrix}$$



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Abelian flavour symmetries

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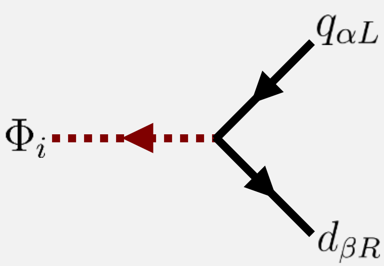

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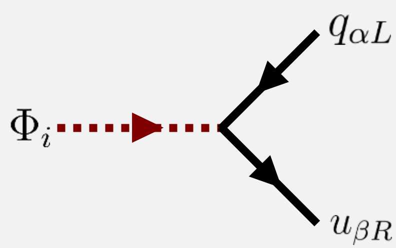

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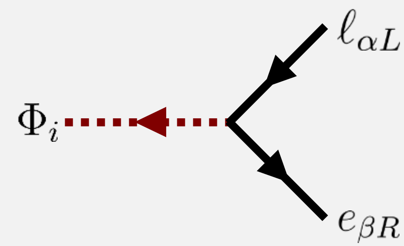
$\beta = 2, 3, 1, 3, 2$

$$\mathbf{M}_e \sim \begin{pmatrix} 0 & 0 & \boxtimes \\ 0 & \boxtimes & 0 \\ \boxtimes & 0 & \boxtimes \end{pmatrix}$$



$i = 1, 2, 1, 2$

$\alpha = 1, 2, 3, 3$

$\beta = 3, 2, 1, 3$

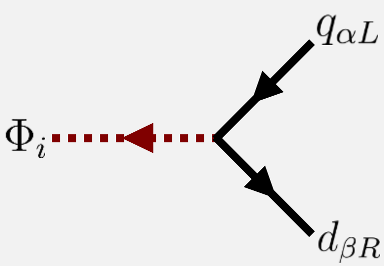
Example

$$\Phi_{1,2} \to q_{1L} + d_{2R}$$

Abelian flavour symmetries

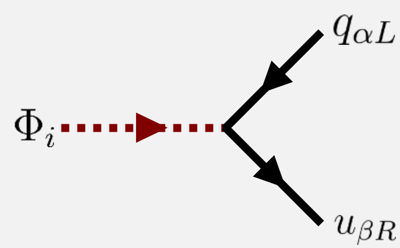
$$-\mathcal{L}_{\text{mass}} = \overline{d_L}\mathbf{M}_d d_R + \overline{u_L}\mathbf{M}_u u_R + \overline{e_L}\mathbf{M}_e e_R + \overline{\nu_L}\mathbf{M}_D^* \nu_R + \frac{1}{2}\overline{\nu_R}\mathbf{M}_R \nu_R^c + \text{H.c.}$$

$$\mathbf{M}_d \sim \begin{pmatrix} 0 & \boxed{0} & \boxtimes \\ 0 & \boxtimes & 0 \\ \boxtimes & 0 & \boxtimes \end{pmatrix}$$



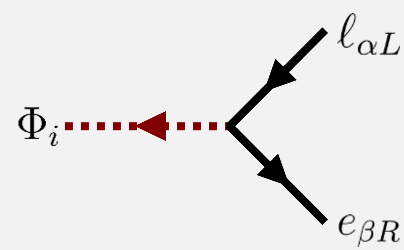
$i = 1, 2, 1, 2$
$\alpha = 1, 2, 3, 3$
$\beta = 3, 2, 1, 3$

$$\mathbf{M}_u \sim \begin{pmatrix} 0 & \boxtimes & \boxtimes \\ \boxtimes & 0 & \boxtimes \\ 0 & \boxtimes & 0 \end{pmatrix}$$



$i = 2, 1, 1, 2, 1$
$\alpha = 1, 1, 2, 2, 3$
$\beta = 2, 3, 1, 3, 2$

$$\mathbf{M}_e \sim \begin{pmatrix} 0 & 0 & \boxtimes \\ 0 & \boxtimes & 0 \\ \boxtimes & 0 & \boxtimes \end{pmatrix}$$



$i = 1, 2, 1, 2$
$\alpha = 1, 2, 3, 3$
$\beta = 3, 2, 1, 3$

Example

$$\cancel{\Phi_{1,2} \to q_{1L} + d_{2R}} \longrightarrow$$

PQ charge is not conserved

$$\chi_{1,2} - \chi_{q1}^L + \chi_{d2}^R \neq 0$$

Maximally-restrictive textures from U(1) symmetries

Procedure

Equivalence classes with the maximum number of zeros

Maximally-restrictive textures from U(1) symmetries

Procedure

Equivalence classes with the maximum number of zeros

↓

Solve system of equations for the PQ charges

Maximally-restrictive textures from U(1) symmetries

Procedure

Equivalence classes with the maximum number of zeros

↓

Solve system of equations for the PQ charges

↓

Test compatibility at the 1σ CL for all observables

Experimental Data

Quarks

Parameter	Best fit $\pm 1\sigma$
$m_d(\times \text{ MeV})$	$4.67^{+0.48}_{-0.17}$
$m_s(\times \text{ MeV})$	$93.4^{+8.6}_{-3.4}$
$m_b(\times \text{ GeV})$	$4.18^{+0.03}_{-0.02}$
$m_u(\times \text{ MeV})$	$2.16^{+0.49}_{-0.26}$
$m_c(\times \text{ GeV})$	1.27 ± 0.02
$m_t(\times \text{ GeV})$	172.69 ± 0.30
$\theta^q_{12}(^\circ)$	13.04 ± 0.05
$\theta^q_{23}(^\circ)$	2.38 ± 0.06
$\theta^q_{13}(^\circ)$	0.201 ± 0.011
$\delta^q(^\circ)$	68.75 ± 4.5

Leptons

Parameter	Best Fit $\pm 1\sigma$
$m_e(\times \text{ keV})$	$510.99895000 \pm 0.00000015$
$m_\mu(\times \text{ MeV})$	$105.6583755 \pm 0.0000023$
$m_\tau(\times \text{ GeV})$	1.77686 ± 0.00012
$\Delta m^2_{21}\ (\times 10^{-5}\text{ eV}^2)$	$7.50^{+0.22}_{-0.20}$
$\lvert\Delta m^2_{31}\rvert\ (\times 10^{-3}\text{ eV}^2)$ [NO]	$2.55^{+0.02}_{-0.03}$
$\lvert\Delta m^2_{31}\rvert\ (\times 10^{-3}\text{ eV}^2)$ [IO]	$2.45^{+0.02}_{-0.03}$
$\theta^\ell_{12}(^\circ)$	34.3 ± 1.0
$\theta^\ell_{23}(^\circ)$[NO]	49.26 ± 0.79
$\theta^\ell_{23}(^\circ)$[IO]	$49.46^{+0.60}_{-0.97}$
$\theta^\ell_{13}(^\circ)$[NO]	$8.53^{+0.13}_{-0.12}$
$\theta^\ell_{13}(^\circ)$[IO]	$8.58^{+0.12}_{-0.14}$
$\delta^\ell(^\circ)$[NO]	194^{+24}_{-22}
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Maximally-restrictive textures from U(1) symmetries

Procedure

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Solve system of equations for the PQ charges

Test compatibility at the 1σ CL for all observables

Add nonzero entry

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Maximally-restrictive textures from U(1) symmetries

Procedure

Equivalence classes with the maximum number of zeros

Solve system of equations for the PQ charges

Test compatibility at the 1σ CL for all observables

Add nonzero entry

Maximally-restrictive textures for $M_{d,u,e,D,R}$ and U(1) charges

Experimental Data

Quarks

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$m_d(\times\ \mathrm{MeV})$	$4.67^{+0.48}_{-0.17}$
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Maximally-Restrictive Quark Textures

U(1) charges

Model	$(\mathbf{M}_d,\mathbf{M}_u)$	$\chi^L_{q\alpha} + \frac{s^2_\beta}{3}$	$\chi^R_{d\alpha} - \frac{2s^2_\beta}{3}$	$\chi^R_{u\alpha} + \frac{4s^2_\beta}{3}$
$\mathrm{Q}_1^{\mathrm{I}}$	$(4^d_3, \mathbf{P}_{12}5^u_1\mathbf{P}_{23})$	$(0,1,2)$	$(2,1,0)$	$(3,2,0)$
$\mathrm{Q}_1^{\mathrm{II}}$		$(0,-1,-2)$	$(-3,-2,-1)$	$(-2,-1,1)$
$\mathrm{Q}_2^{\mathrm{I}}$	$(4^d_3, \mathbf{P}_{123}5^u_1\mathbf{P}_{12})$	$(0,1,2)$	$(2,1,0)$	$(3,0,1)$
$\mathrm{Q}_2^{\mathrm{II}}$		$(0,-1,-2)$	$(-3,-2,-1)$	$(-2,1,0)$
$\mathrm{Q}_3^{\mathrm{I}}$	$(5^d_1, \mathbf{P}_{12}4^u_3)$	$(0,-1,1)$	$(1,-2,0)$	$(2,1,0)$
$\mathrm{Q}_3^{\mathrm{II}}$		$(0,1,-1)$	$(-2,1,-1)$	$(-1,0,1)$
$\mathrm{Q}_4^{\mathrm{I}}$	$(5^d_1, \mathbf{P}_{321}4^u_3\mathbf{P}_{23})$	$(0,-1,1)$	$(1,-2,0)$	$(-1,1,0)$
$\mathrm{Q}_4^{\mathrm{II}}$		$(0,1,-1)$	$(-2,1,-1)$	$(2,0,1)$

Maximally restrictive mass matrices

$$4^d_3 \sim \begin{pmatrix} 0 & 0 & \times \\ 0 & \times & \times \\ \times & \times & 0 \end{pmatrix}$$

$$5^d_1 \sim \begin{pmatrix} 0 & 0 & \times \\ 0 & \times & 0 \\ \times & 0 & \times \end{pmatrix}$$

$$\mathbf{P}_{12}5^u_1\mathbf{P}_{23} \sim \begin{pmatrix} 0 & 0 & \times \\ 0 & \bullet & 0 \\ \times & \times & 0 \end{pmatrix}$$

$$\mathbf{P}_{123}5^u_1\mathbf{P}_{12} \sim \begin{pmatrix} 0 & \times & \bullet \\ 0 & 0 & \times \\ \times & 0 & 0 \end{pmatrix}$$

$$\mathbf{P}_{12}4^u_3 \sim \begin{pmatrix} 0 & \bullet & \times \\ 0 & 0 & \times \\ \times & \times & 0 \end{pmatrix}$$

$$\mathbf{P}_{321}4^u_3\mathbf{P}_{23} \sim \begin{pmatrix} 0 & \bullet & \times \\ \times & 0 & \times \\ 0 & \times & 0 \end{pmatrix}$$

Maximally-Restrictive Lepton Textures

U(1) charges

Model	$(\mathbf{M}_e,\mathbf{M}_D,\mathbf{M}_R)$	χ_σ	$\chi^L_{\ell_\alpha} - s^2_\beta$	$\chi^R_{e_\alpha} - 2s^2_\beta$	$\chi^R_{\nu_j}$
L_1	$(4^e_3, 2^D_1, 2^R_1)$	$1/2$	$(-3/2, -1/2, 1/2)$	$(1/2, -1/2, -3/2)$	$(-1/2, 1/2)$
L_2	$(4^e_3, 3^D_1, 1^R_{1,1})$	1	$(0, 1, 2)$	$(2, 1, 0)$	$(1, 0)$
L_3	$(4^e_3, 3^D_1, 1^R_{1,2})$	$1/2$	$(-1/4, 3/4, 7/4)$	$(7/4, 3/4, -1/4)$	$(3/4, -1/4)$
L_4	$(4^e_3, 3^D_2, 1^R_2)$	1	$(-3/2, -1/2, 1/2)$	$(1/2, -1/2, -3/2)$	$(-1/2, 3/2)$
L_5	$(4^e_3, 3^D_2, 1^R_{1,3})$	1	$(-5/2, -3/2, -1/2)$	$(-1/2, -3/2, -5/2)$	$(-3/2, 1/2)$
L_6	$(4^e_3, 3^D_3, 1^R_{1,3})$	1	$(-3/2, -1/2, 1/2)$	$(1/2, -1/2, -3/2)$	$(-3/2, 1/2)$
L_7	$(4^e_3, 3^D_3, 1^R_2)$	1	$(-1/2, 1/2, 3/2)$	$(3/2, 1/2, -1/2)$	$(-1/2, 3/2)$
L_8	$(4^e_3, 3^D_4, 1^R_{1,4})$	1	$(-3, -2, -1)$	$(-1, -2, -3)$	$(-1, 0)$
L_9	$(4^e_3, 3^D_4, 1^R_{1,3})$	$1/2$	$(-11/4, -7/4, -3/4)$	$(-3/4, -7/4, -11/4)$	$(-3/4, 1/4)$
L_{10}	$(5^e_1, 2^D_2, 1^R_{1,4})$	1	$(-1, -2, 0)$	$(0, -3, -1)$	$(-1, 0)$
L_{11}	$(5^e_1, 2^D_2, 1^R_{1,3})$	$1/2$	$(-3/4, -7/4, 1/4)$	$(1/4, -11/4, -3/4)$	$(-3/4, 1/4)$

Maximally restrictive mass matrices

$$4^e_3 \sim \begin{pmatrix} 0 & 0 & \times \\ 0 & \times & \times \\ \times & \times & 0 \end{pmatrix}$$

$$5^e_1 \sim \begin{pmatrix} 0 & 0 & \times \\ 0 & \times & 0 \\ \times & 0 & \times \end{pmatrix}$$

$$1^R_1 \sim \begin{pmatrix} 0 & \times \\ \cdot & \times \end{pmatrix}$$

$$1^R_2 \sim \begin{pmatrix} \times & \times \\ \cdot & 0 \end{pmatrix}$$

$$2^R_1 \sim \begin{pmatrix} 0 & \times \\ \cdot & 0 \end{pmatrix}$$

$$2^D_1 \sim \begin{pmatrix} \bullet & 0 \\ \bullet & \bullet \\ 0 & \bullet \end{pmatrix}$$

$$2^D_2 \sim \begin{pmatrix} \bullet & \bullet \\ \bullet & 0 \\ 0 & \bullet \end{pmatrix}$$

$$3^D_1 \sim \begin{pmatrix} \bullet & \bullet \\ \bullet & 0 \\ 0 & 0 \end{pmatrix}$$

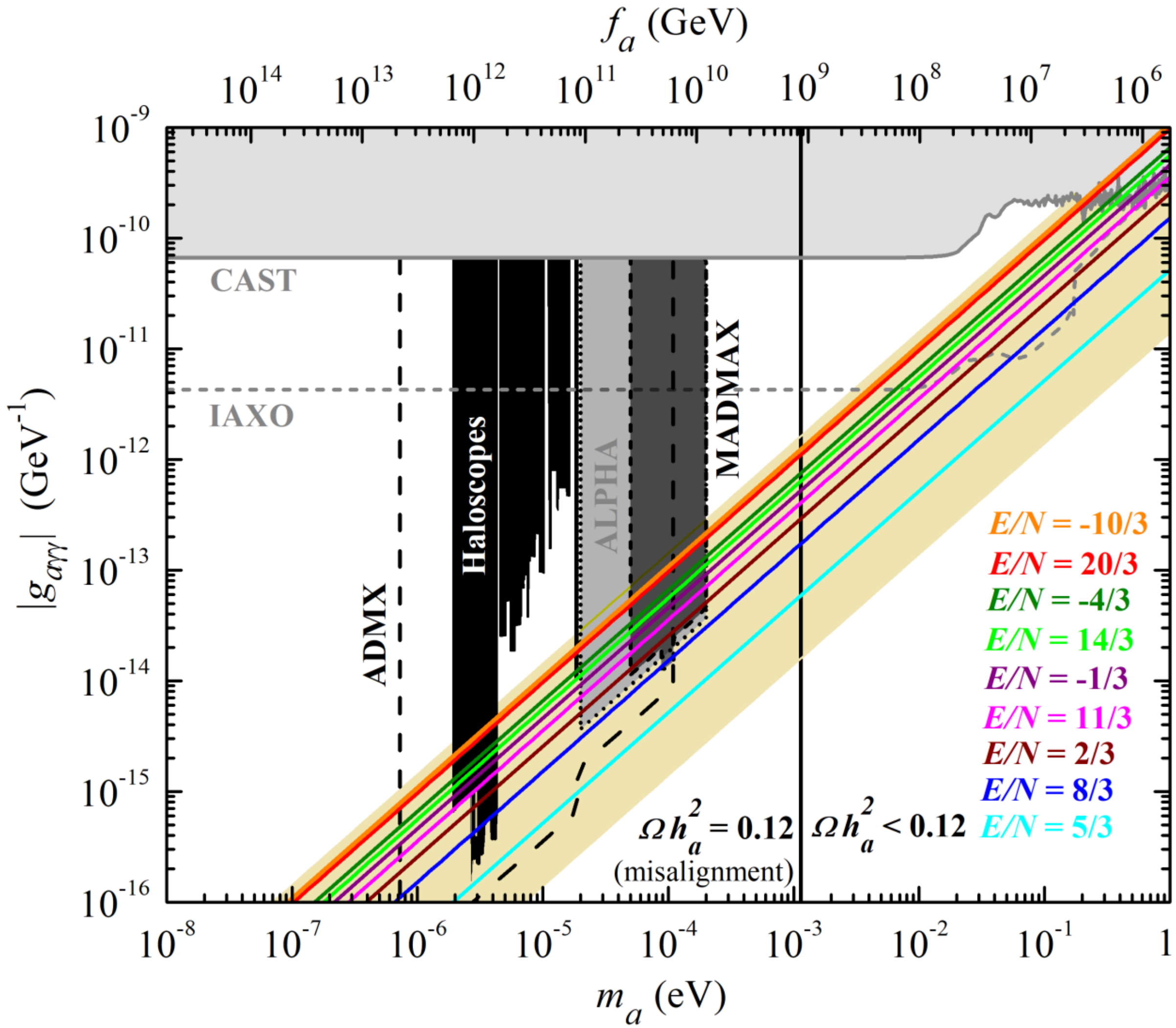
$$3^D_2 \sim \begin{pmatrix} \bullet & 0 \\ \bullet & 0 \\ 0 & \bullet \end{pmatrix}$$

$$3^D_3 \sim \begin{pmatrix} \bullet & 0 \\ 0 & \bullet \\ 0 & \bullet \end{pmatrix}$$

$$3^D_4 \sim \begin{pmatrix} 0 & 0 \\ \bullet & 0 \\ \bullet & \bullet \end{pmatrix}$$

Axion-to-Photon Coupling

Models	E/N
$(Q_2^{II}, L_{1\text{-}9})$	-10/3
$(Q_2^{II}, L_{10,11})$	-4/3
$(Q_1^{II}, L_{1\text{-}9})$	-1/3
$(Q_{1,2/3,4}^{II,I/II,I}, L_{10,11/1\text{-}9})$	2/3
$(Q_3^{II}, L_{10,11})$	5/3
$(Q_{1,2/3,4}^{I}, L_{1\text{-}9/10,11})$	8/3
$(Q_3^{I}, L_{1\text{-}9})$	11/3
$(Q_4^{II}, L_{10,11})$	14/3
$(Q_4^{II}, L_{1\text{-}9})$	20/3



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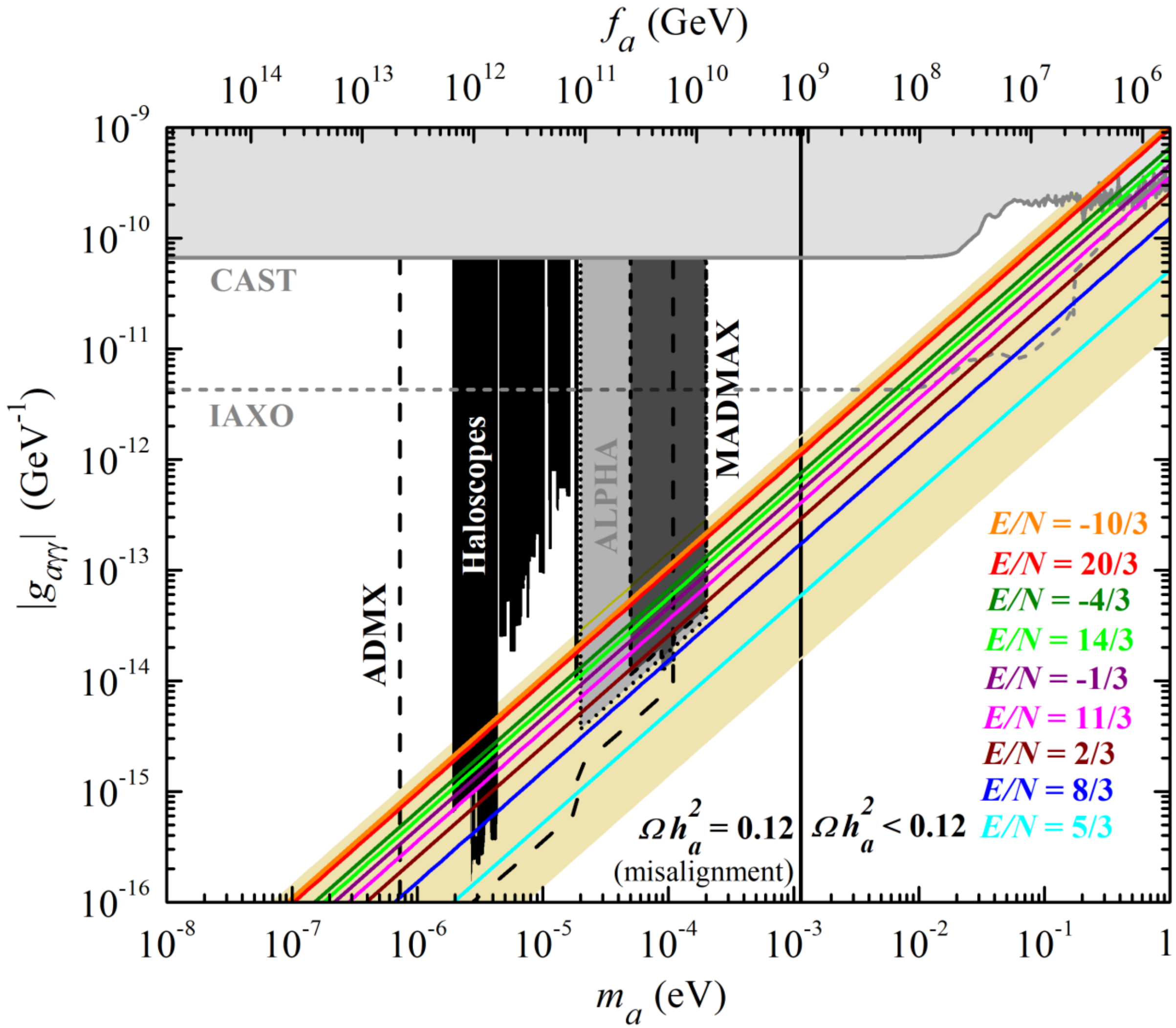
$(Q_2^{II}, L_{10,11})$	-4/3
$(Q_1^{II}, L_{1\text{-}9})$	-1/3
$(Q_{1,2/3,4}^{II,I/II,I}, L_{10,11/1\text{-}9})$	2/3
$(Q_3^{II}, L_{10,11})$	5/3
$(Q_{1,2/3,4}^{I}, L_{1\text{-}9/10,11})$	8/3
$(Q_3^{I}, L_{1\text{-}9})$	11/3
$(Q_4^{II}, L_{10,11})$	14/3
$(Q_4^{II}, L_{1\text{-}9})$	20/3



Axion-to-photon coupling allows to probe the different models at **helioscope** and **haloscope** experiments

Flavour Violation in the Softly-Broken U(1) 2HDM

Requiring $v_\sigma \gg v_{1,2}$ for an **"invisible" axion**, the **singlet** effectively **decouples** from the scalar particles of the **2HDM**

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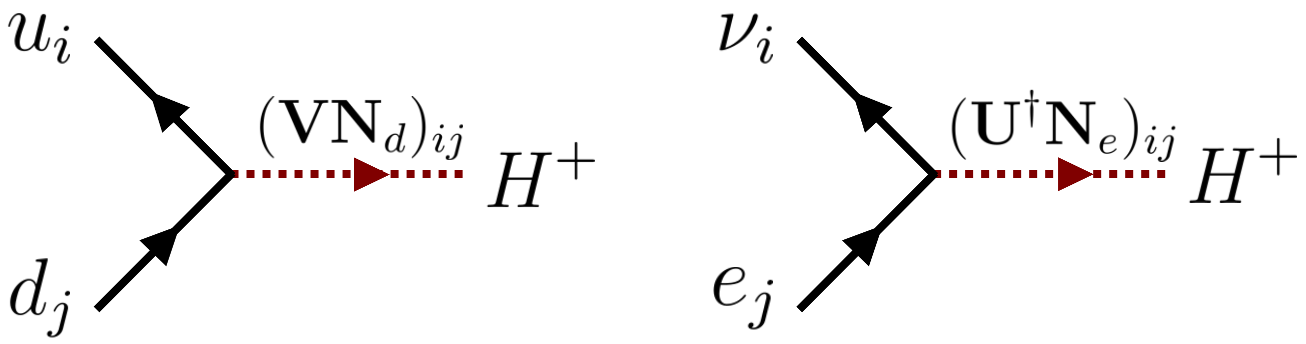
FCCC in the 2HDM



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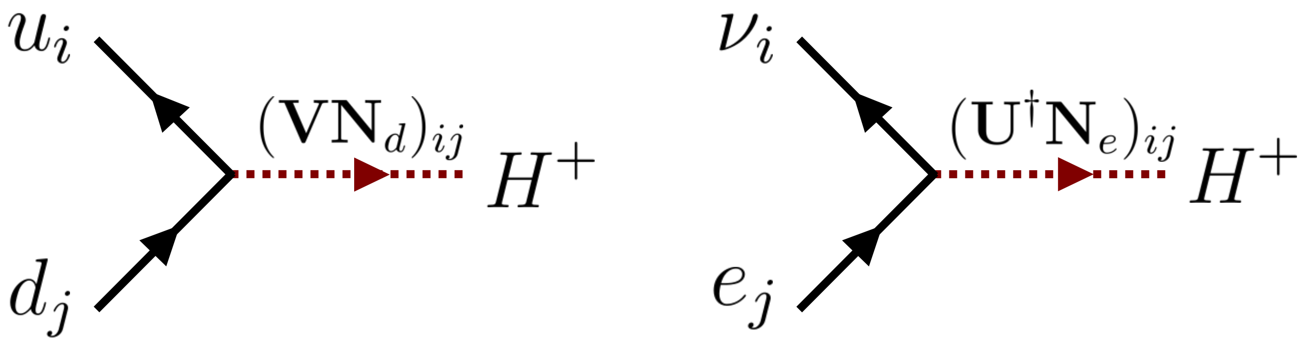

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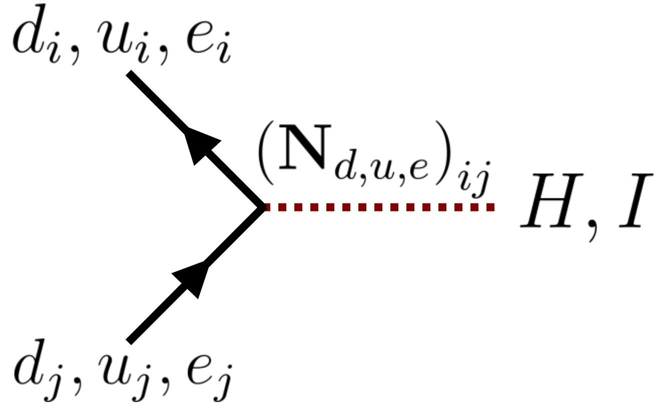

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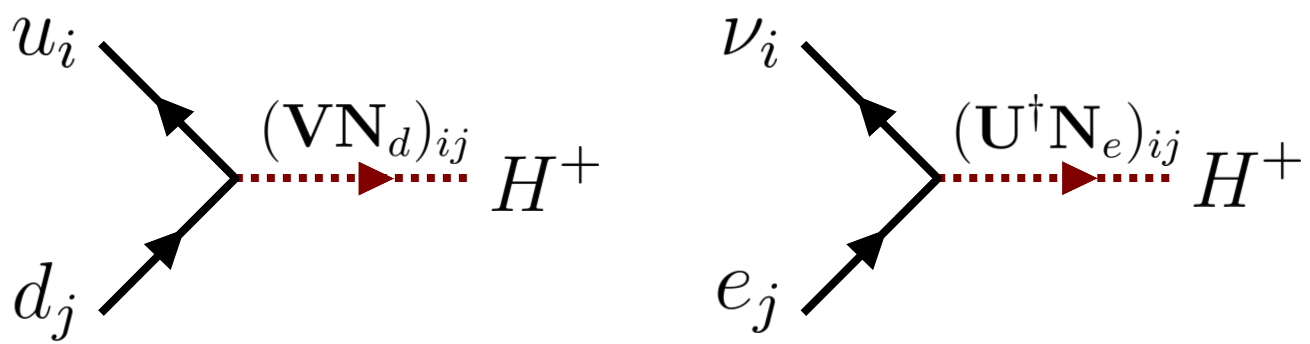
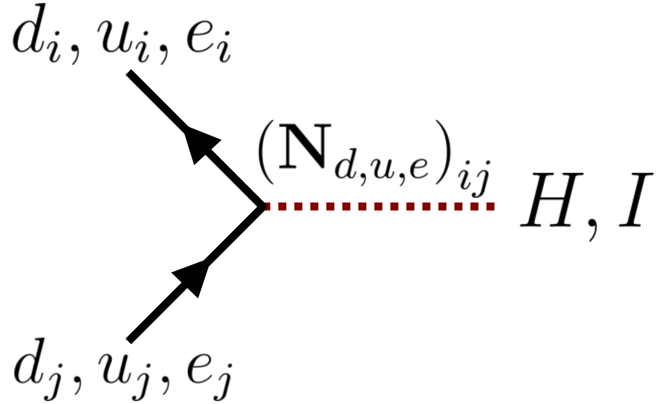


FCNC in the 2HDM



How are these processes controlled in our models?

Flavour Violation in the Softly-Broken U(1) 2HDM

There is a **"Decoupled"** entry in the matrices of **type "5"**

$$\mathbf{M}_f = \mathbf{P_b} \begin{pmatrix} 0 & 0 & a_1 = \frac{m_{f_2} m_{f_1}}{a_2} \\ 0 & a_3 = m_{f_1} & 0 \\ a_2 & 0 & a_4 = \frac{\sqrt{\left(a_2^2 - m_{f_2}^2\right)\left(m_{f_3}^2 - a_5\right)}}{a_2} \end{pmatrix} \mathbf{P_c}$$

Flavour Violation in the Softly-Broken U(1) 2HDM

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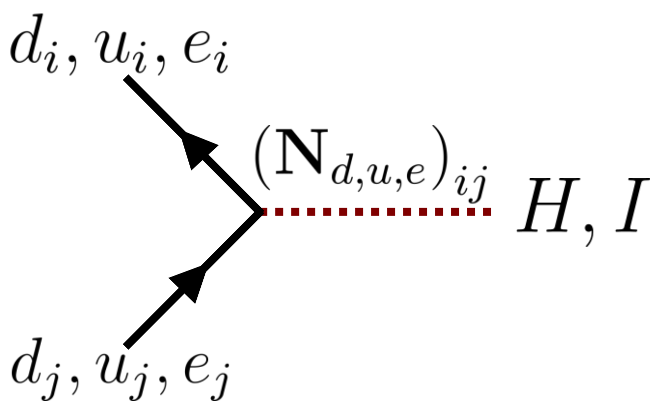
Leads to **zeros** in the **$\mathbf{N}_k$ matrices**

$$5^{d,u,e} : \mathbf{N}_{d,u,e} \sim \begin{pmatrix} \times & 0 & 0 \\ 0 & \times & \times \\ 0 & \times & \times \end{pmatrix}, 5^{s,c,\mu} : \mathbf{N}_{d,u,e} \sim \begin{pmatrix} \times & 0 & \times \\ 0 & \times & 0 \\ \times & 0 & \times \end{pmatrix}, 5^{b,t,\tau} : \mathbf{N}_{d,u,e} \sim \begin{pmatrix} \times & \times & 0 \\ \times & \times & 0 \\ 0 & 0 & \times \end{pmatrix}$$



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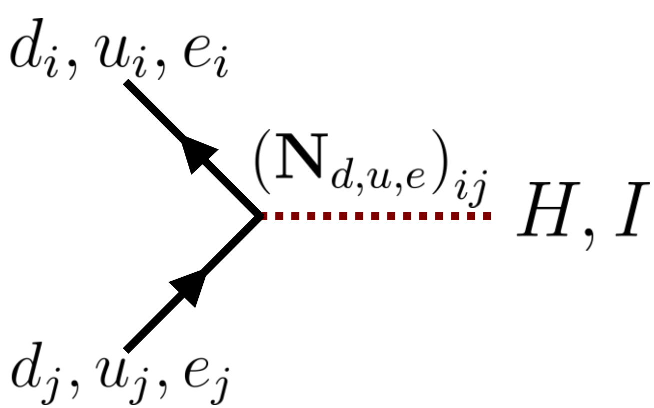

FCNCs are controlled

J.R. R, H.B. Câmara, R.G. Felipe, F.R. Joaquim;
PRD 110 (2024) 3, 035027

Flavor-Violating Axion Couplings to Fermions

Effective Axion-Fermion Interactions

$$\mathcal{L}_{aff} = \frac{\partial_\mu a}{2 f_a} \overline{f_\alpha} \gamma^\mu \left(\mathbf{C}^{V,f}_{\alpha\beta} + \mathbf{C}^{A,f}_{\alpha\beta} \gamma_5 \right) f_\beta$$

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Flavor-Violating Axion Couplings to Fermions

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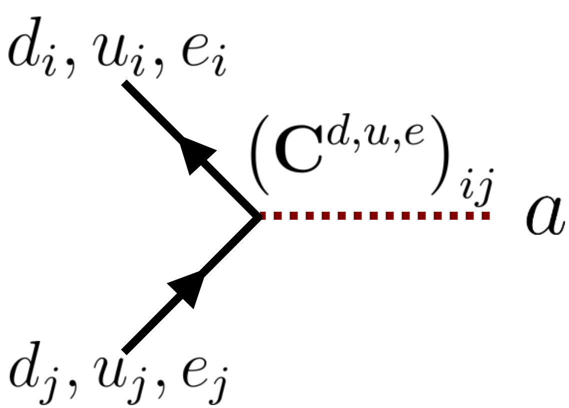
The matrices of **type "5"** also lead to **zeros** in the **$\mathbf{C}^f$ matrices**

$$5^{d,u,e} : \mathbf{C}^{d,u,e} \sim \begin{pmatrix} \times & 0 & 0 \\ 0 & \times & \times \\ 0 & \times & \times \end{pmatrix} , 5^{s,c,\mu} : \mathbf{C}^{d,u,e} \sim \begin{pmatrix} \times & 0 & \times \\ 0 & \times & 0 \\ \times & 0 & \times \end{pmatrix} , 5^{b,t,\tau} : \mathbf{C}^{d,u,e} \sim \begin{pmatrix} \times & \times & 0 \\ \times & \times & 0 \\ 0 & 0 & \times \end{pmatrix}$$



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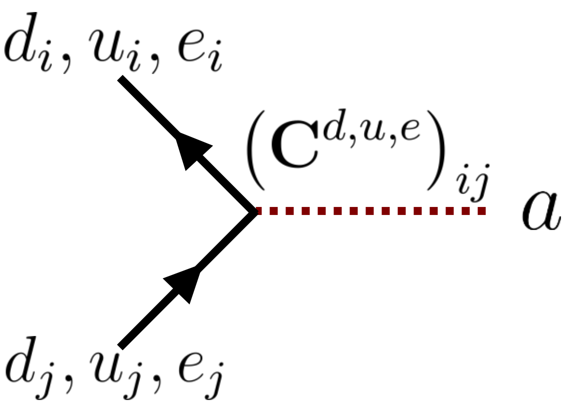
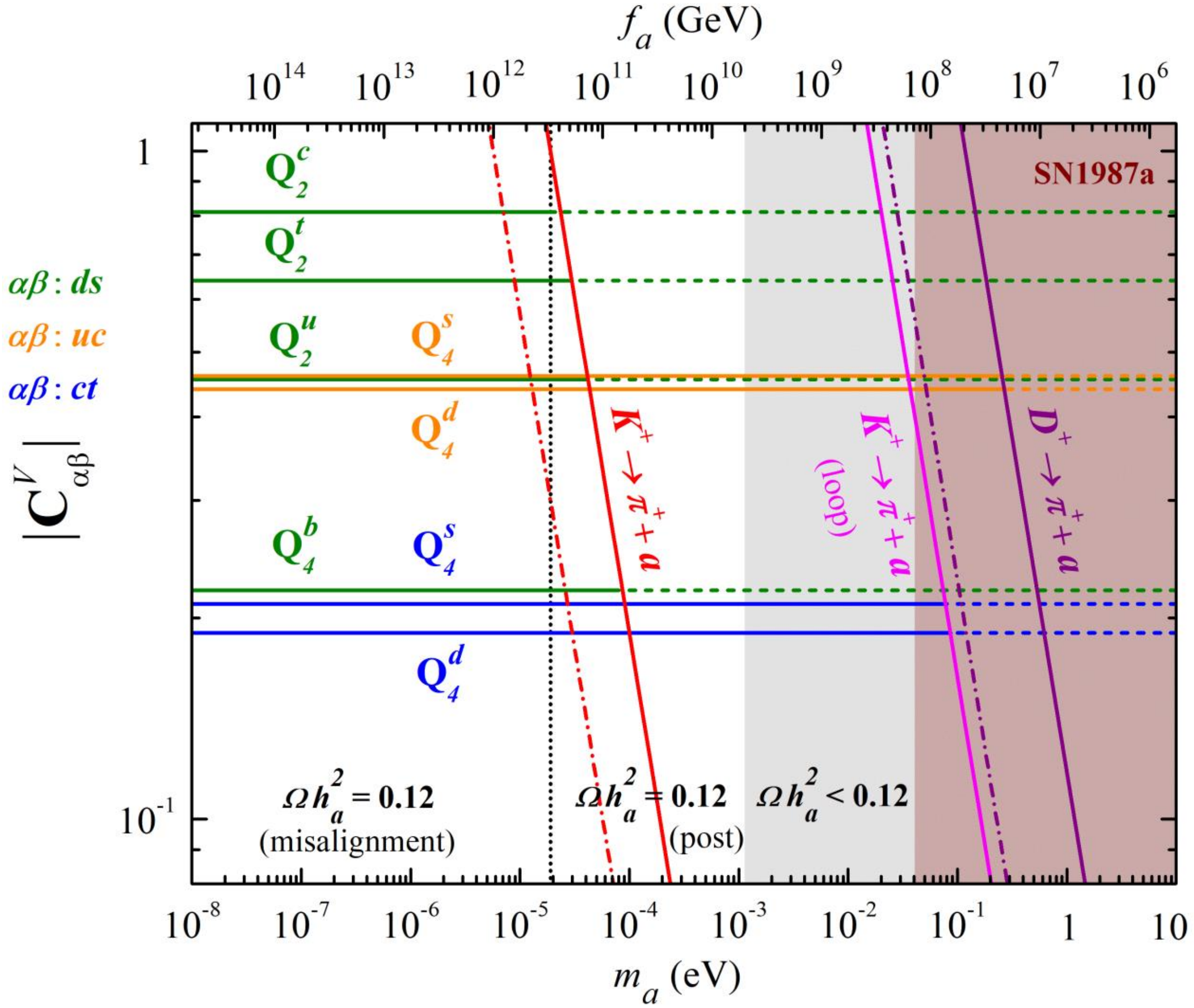


$\longrightarrow$ **FCNCs are again controlled**

Flavor-Violating Axion Couplings to Quarks ($N_{\mathrm{DW}} = 1$)



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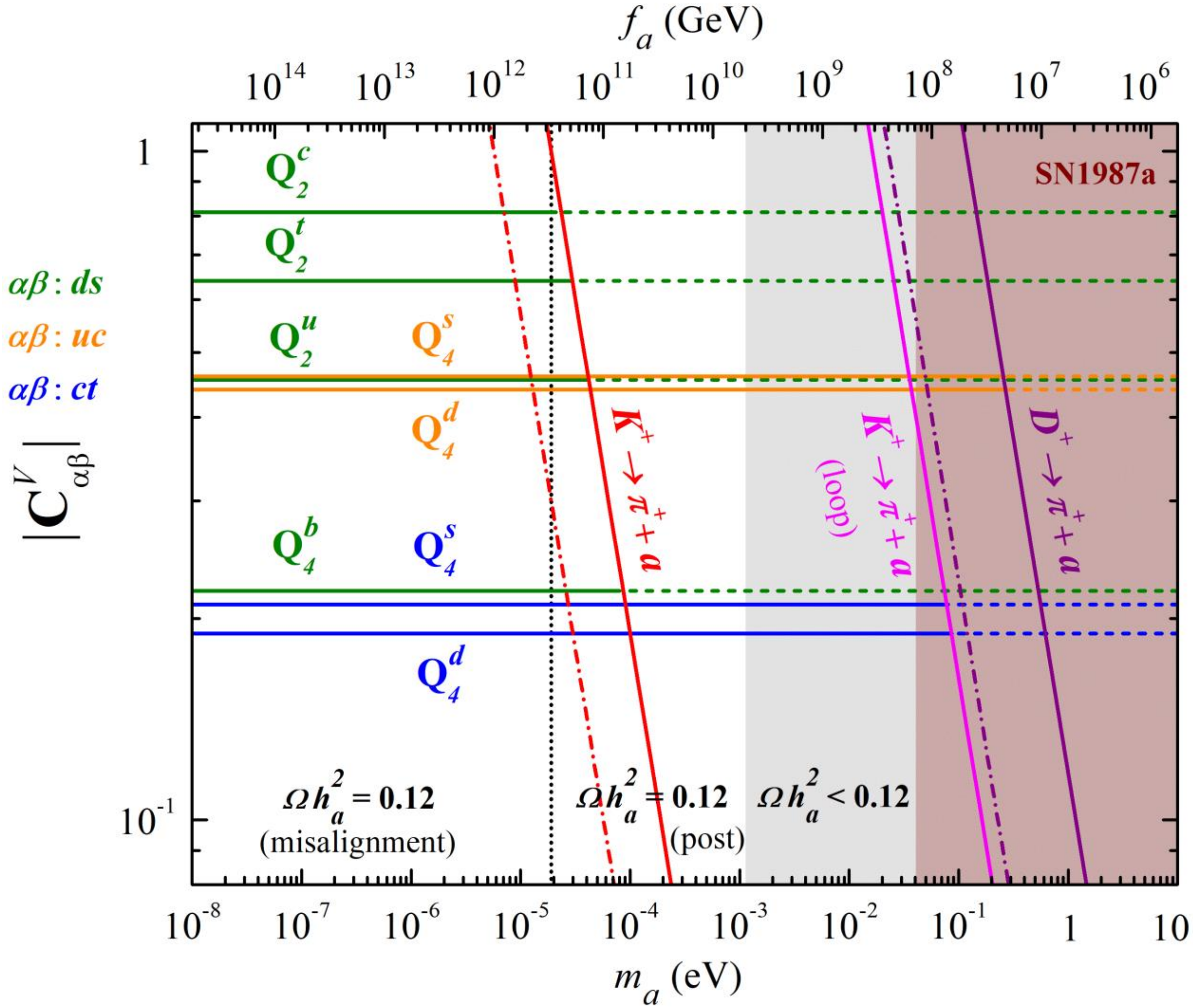
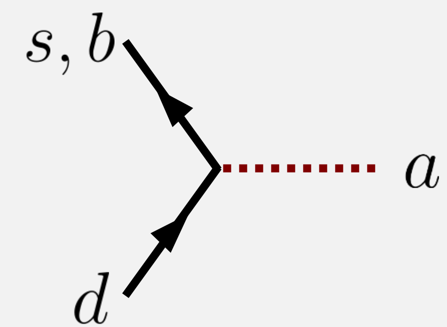


For the model $\mathbf{Q_4^d}$:

$$\mathbf{C}^d \sim \begin{pmatrix} \times & 0 & 0 \\ 0 & \times & \times \\ 0 & \times & \times \end{pmatrix}$$



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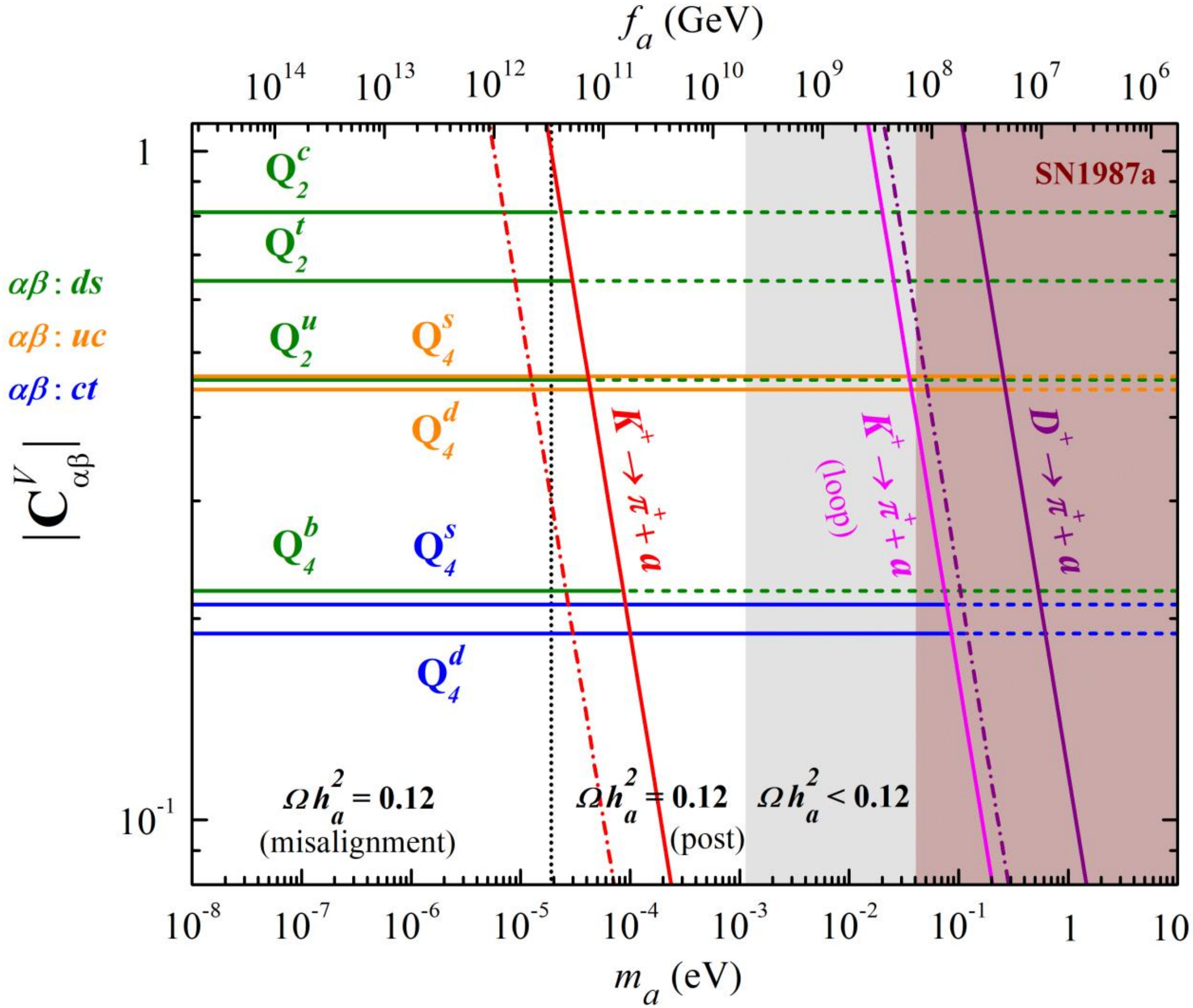

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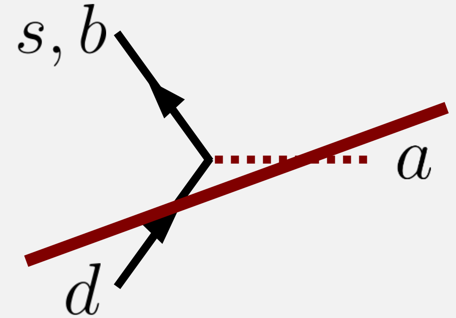

✓ $\mathrm{K}\,(d\bar{s}) \to \pi^+ + a$

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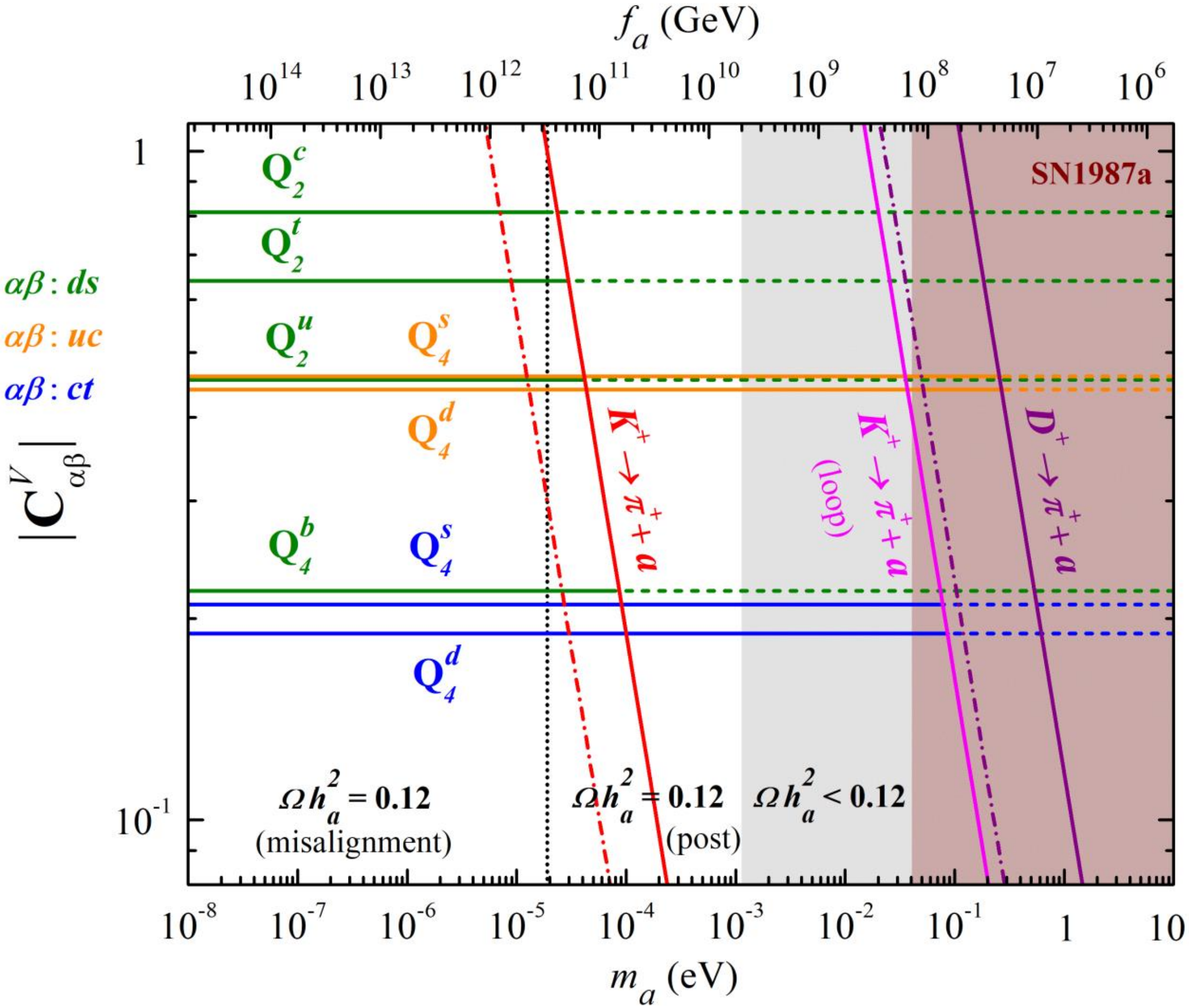

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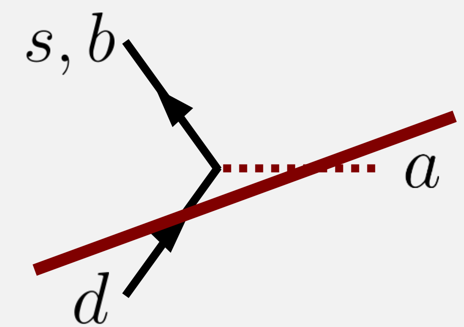
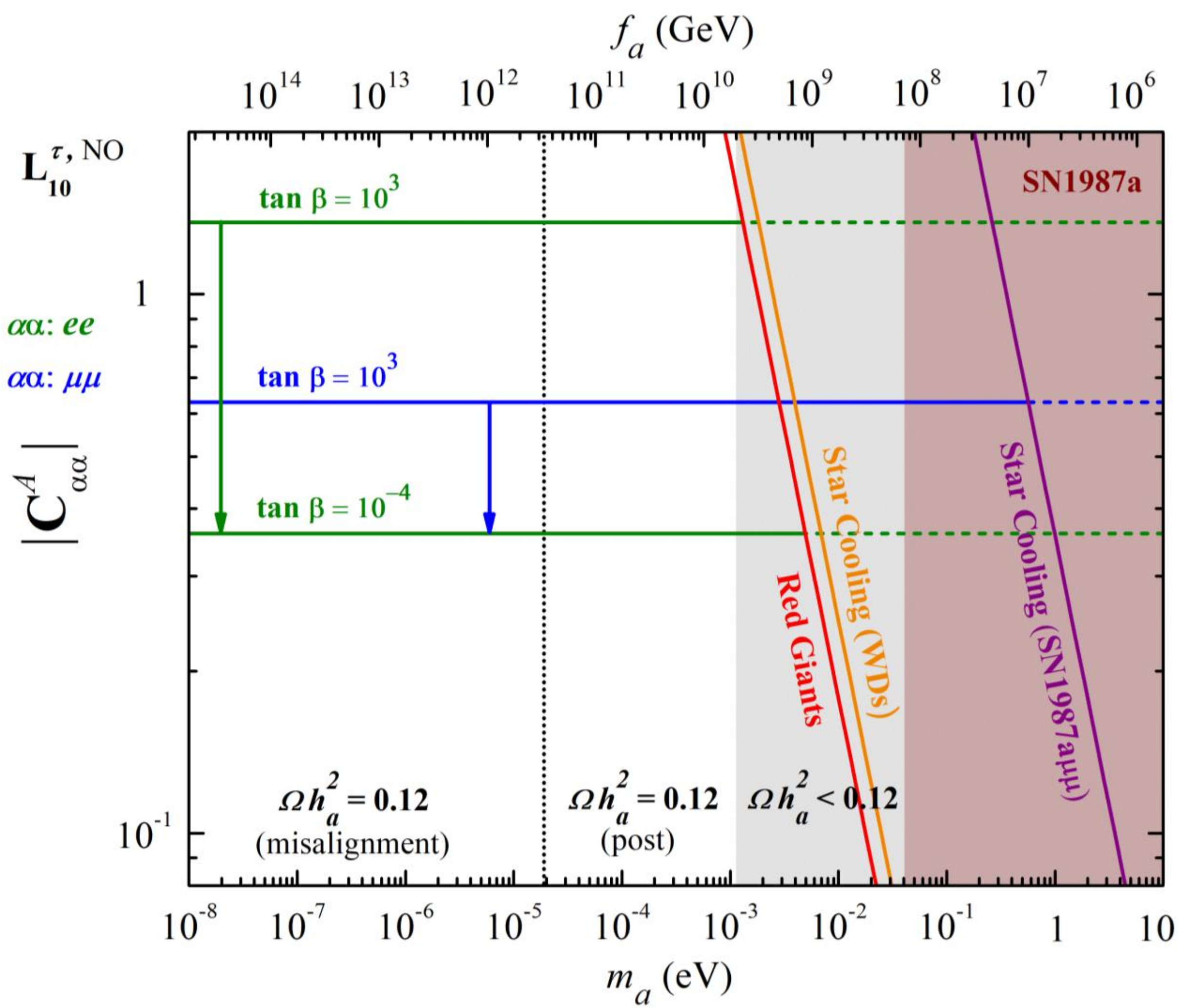


✓ $K\,(d\bar{s}) \to \pi^+ + a$

This highlights the **effectiveness of minimal flavoured PQ symmetries** in aligning **frameworks with highly constrained observations**

Axion Couplings to Leptons ($N_{\mathrm{DW}} = 1$)



Flavor-conserving couplings are **not automatically suppressed** and **depend** on $\tan\beta = v_2/v_1$

Axion Couplings to Fermions ($N_{\mathrm{DW}} = 1$)

Axion mass upper bound (meV)

Model	$Q_4^{d,s}$
L_2	$[1.8, 5.6]$
L_4	$[0.9, 1.3]$
L_5	$[1.0, 1.6]$
L_6	$[1.8, 5.4]$
L_7	$[1.2, 2.2]$
L_8	$[1.0, 1.6]$
L_{10}^e	$[2.5, 32.7]$
L_{10}^μ	$[2.3, 15.8]$
L_{10}^τ	$[1.9, 6.8]$

Model	Q_2^u ; Q_2^c ; Q_2^t ; Q_4^b
All lepton models	3.7×10^{-2}
	2.1×10^{-2}
	1.5×10^{-1}
	7.8×10^{-2}

- **Lepton constraints** set the **axion mass bound** in the ***d* or *s* decoupled models**
- Therefore, the **axion mass** can be up to **two orders of magnitude larger than in the other scenarios**
- As a result, the **whole post-inflationary region remains viable** while still **accommodating flavour-violating axion couplings**

Summary and Outlook

Work done:

- Study of the theoretical framework of the **minimal νDFSZ for flavour**;
- Identification of the **maximally-restrictive pairs of quark and lepton mass matrices** compatible with current masses, mixing and CP violation data;
- **Axion-photon** couplings computed for different models;
- Phenomenology of axion couplings to quarks and charged leptons, with emphasis on flavor-violating terms.

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Thank you !