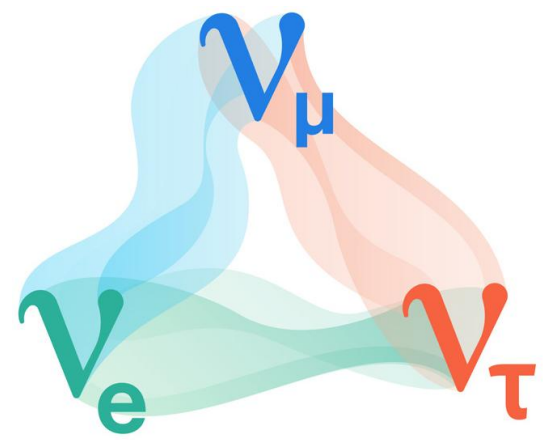# Flavored Peccei-Quinn symmetries in the minimal νDFSZ model

H. B. Câmara, F. R. Joaquim, J. R. Rocha
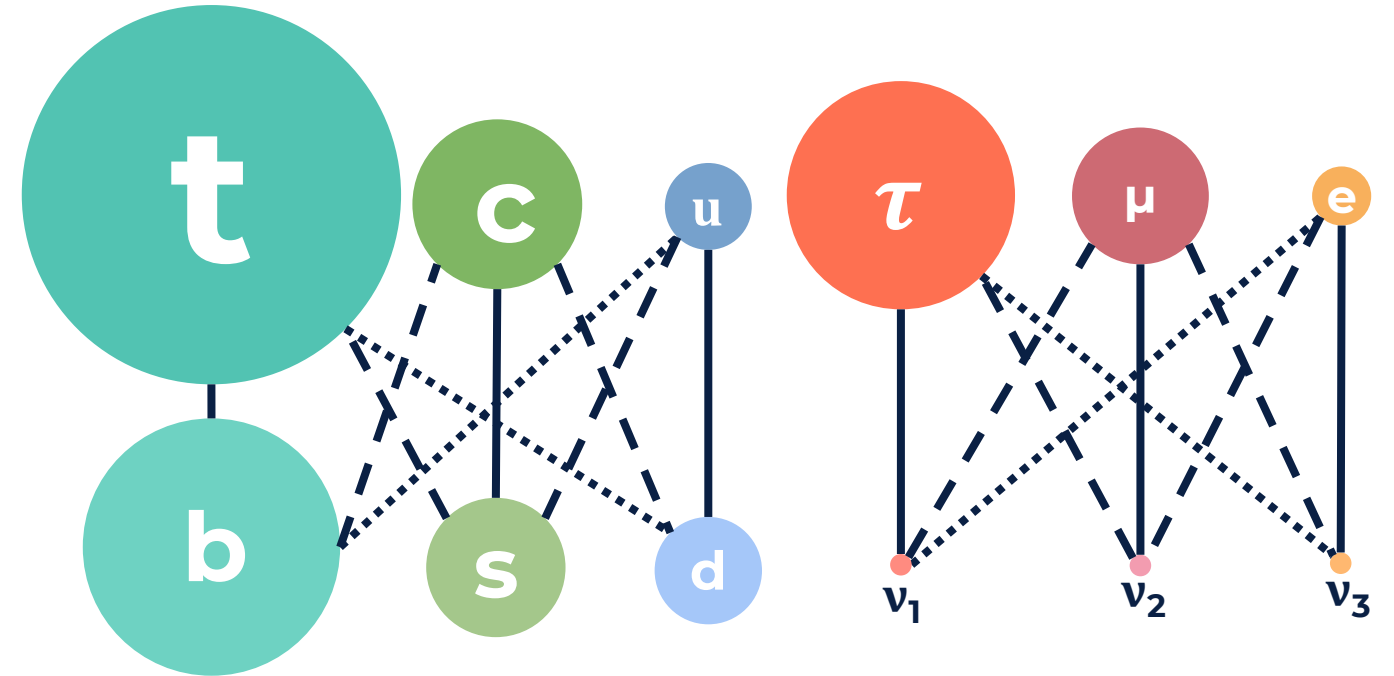
The problems

Neutrino Oscillations

Neutrinos are **massive**, contrarily to what is predicted by the Standard Model (SM).

Flavour Puzzle

The SM **does not explain** the observed **fermion masses and mixing**.

Strong CP Problem

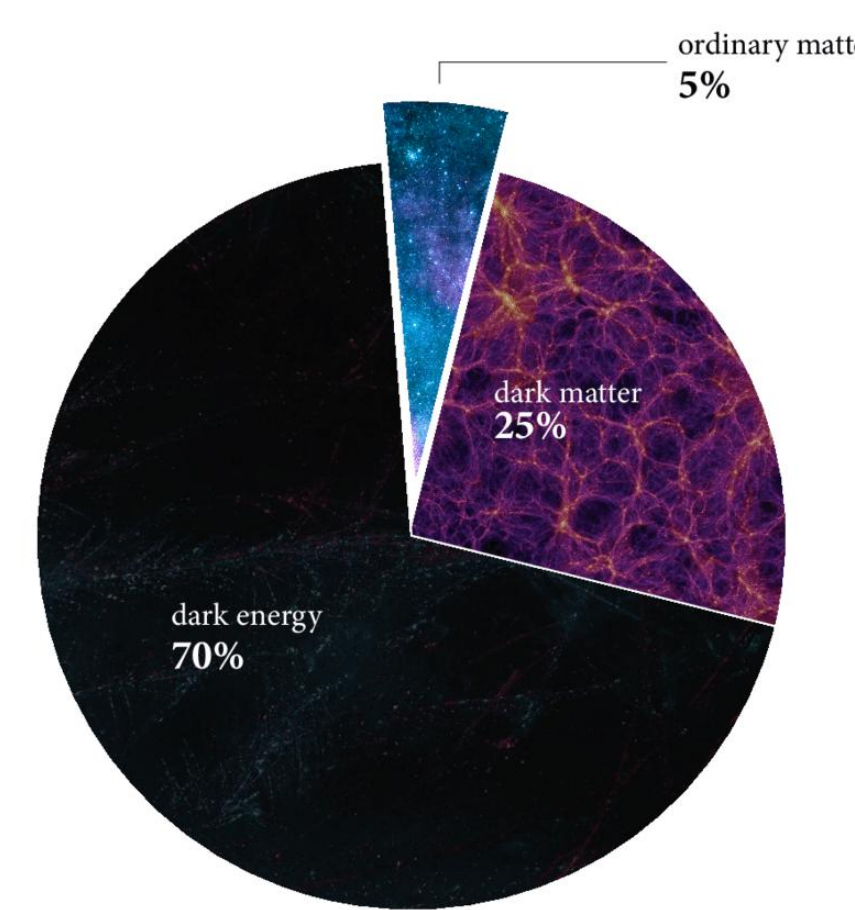The **neutron electric dipole moment has not been observed**, thus placing the bound

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

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

suggesting that strong interactions preserve CP symmetry, **but why?**
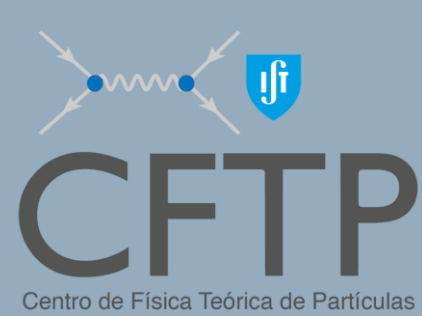
Dark Matter (DM)

Cosmological evidence shows that **26.8% of the Universe's matter is DM**, requiring a **stable, non-baryonic, electrically neutral**, and **cold particle** to account for its observed abundance.

ordinary matter 5%
dark matter 25%
dark energy 70%

The solution

Flavored Peccei-Quinn (PQ) Symmetries

We study models where the flavor symmetry **maximally restricts** fermion mass matrices, leaving the **least possible number of parameters** required to reproduce masses, mixings, and CP violation data.

- **Flavor charge conservation** generates **texture zeros** in the mass matrices:

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

- **Our twist:** the flavor symmetry is promoted to a **PQ symmetry**, so in the low energy effective theory:

$$\mathcal{L}_\theta = \left(\bar{\theta} + \frac{Na}{v_a}\right)\frac{g_s^2}{32\pi^2}G_{\mu\nu}^a\tilde{G}_a^{\mu\nu}$$

$$\langle a \rangle_k = (-\bar{\theta} + 2\pi k)\frac{v_a}{N}$$

Type-I SeeSaw

After EWSB neutrinos gain a **Majorana mass term**.
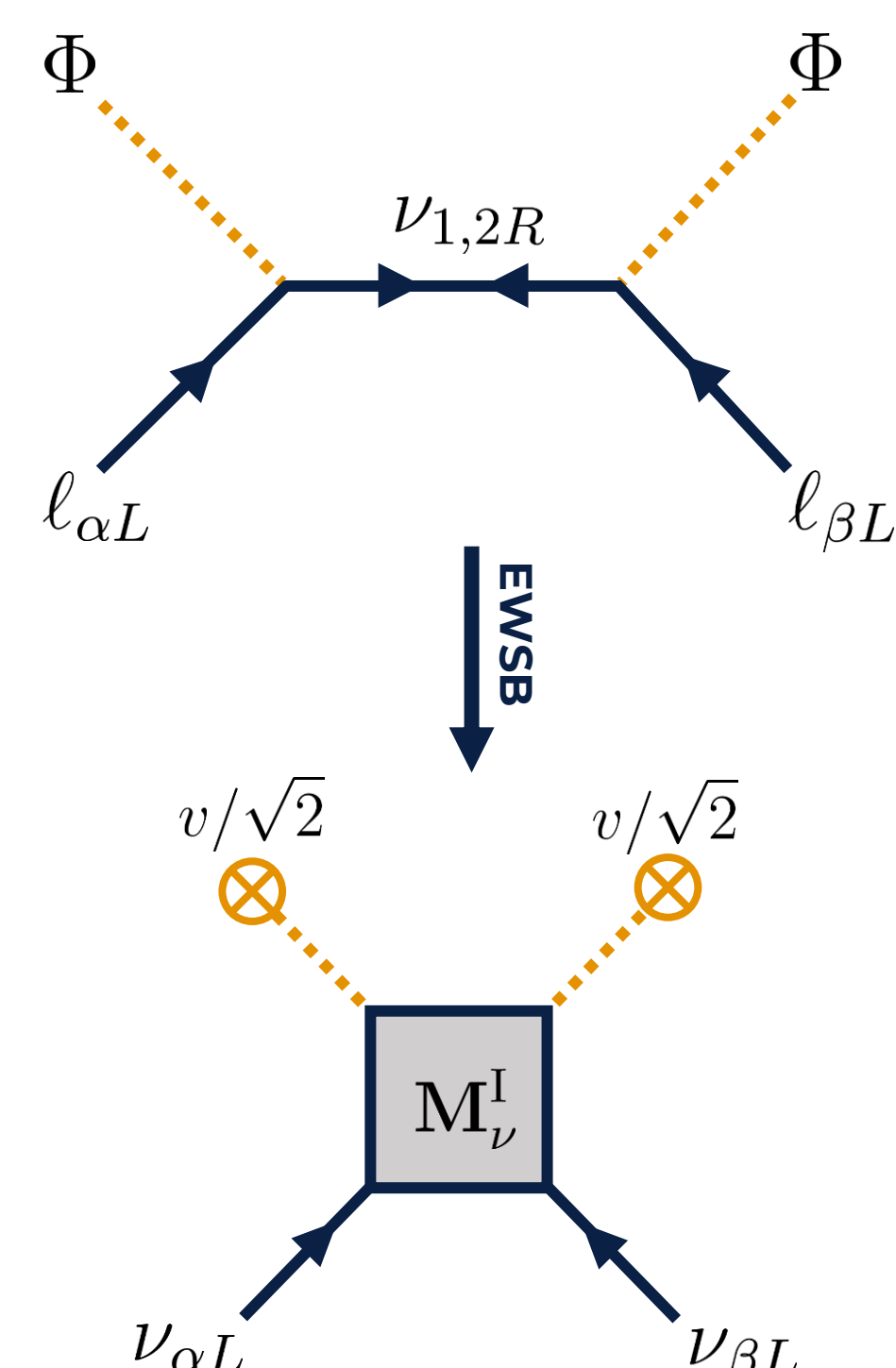
A new class of models where neutrino masses are generated via a type-I Seesaw, while the PQ symmetry simultaneously addresses the strong CP problem and the flavor puzzle. The predicted axion (a) naturally accounts for Dark Matter.

The results

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

We focus on models with **domain wall number $N_{\mathrm{DW}} = 1$**. In this case, the discrete vacuum structure left after PQ symmetry breaking does not result in a cosmological domain wall problem.
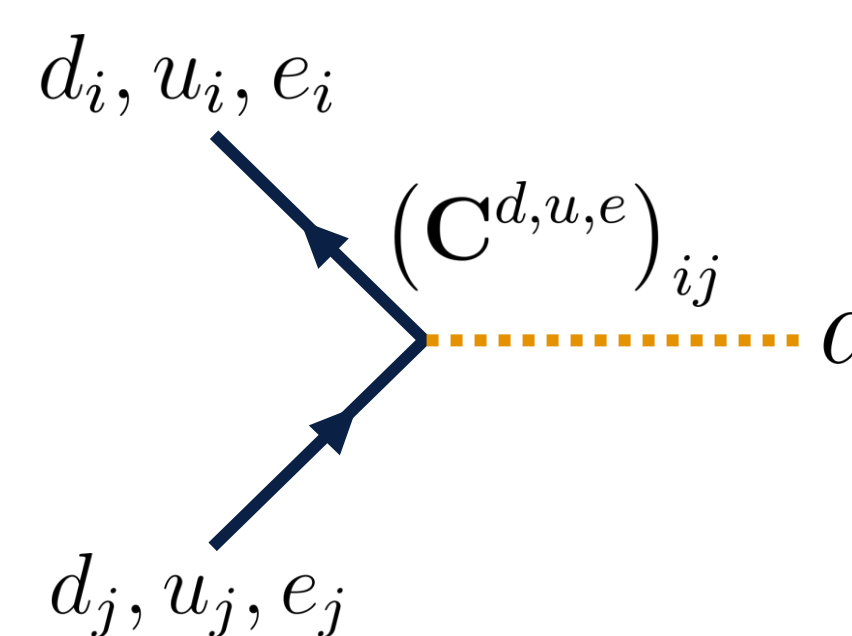
$$5^{d,u,e} : \mathbf{C}^{d,u,e} \sim \begin{pmatrix} \times & 0 & 0 \\ 0 & \times & \times \\ 0 & \times & \times \end{pmatrix}, \quad 5^{s,c,\mu} : \mathbf{C}^{d,u,e} \sim \begin{pmatrix} \times & 0 & \times \\ 0 & \times & 0 \\ \times & 0 & \times \end{pmatrix}, \quad 5^{b,t\tau} : \mathbf{C}^{d,u,e} \sim \begin{pmatrix} \times & \times & 0 \\ \times & \times & 0 \\ 0 & 0 & \times \end{pmatrix}$$

In the d- or s-decoupled models, the most severely constrained flavor-violating axion couplings are forbidden, and as a result the full post-inflationary region remains viable.

JOSÉ ROCHA

Student @ CFTP (2022-2025)

Centro de Física Teórica de Partículas (CFTP)

CFTP
Centro de Física Teórica de Partículas

jose.r.rocha@tecnico.ulisboa.pt

Supervisor:
Filipe Joaquim (CFTP, IST)

2022: BSc in Engineering Physics

LEFT
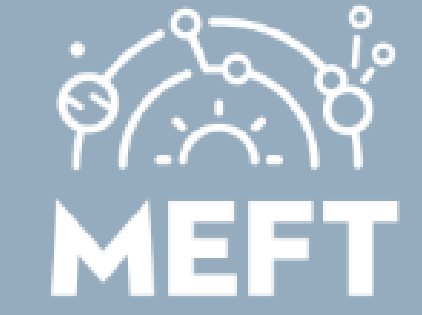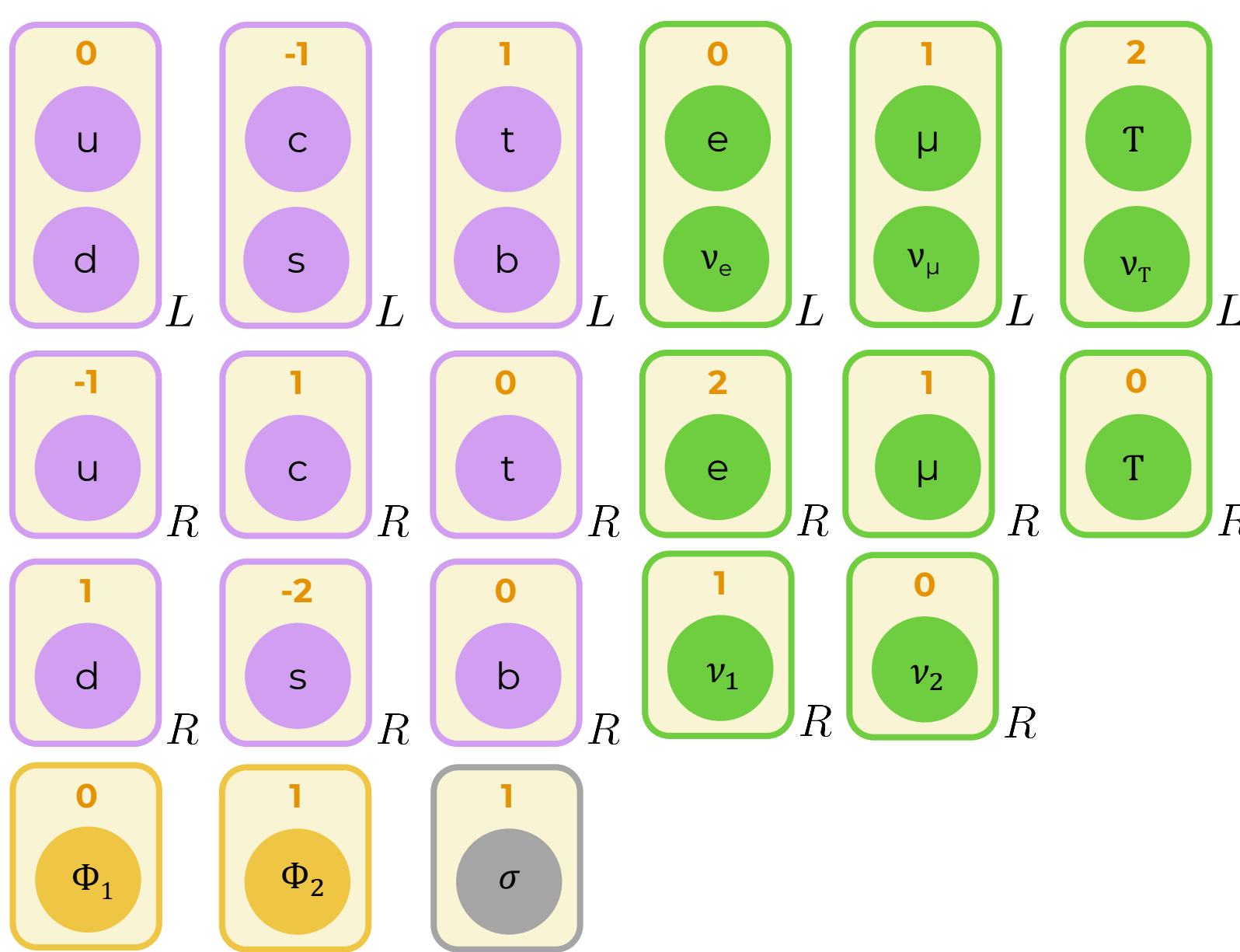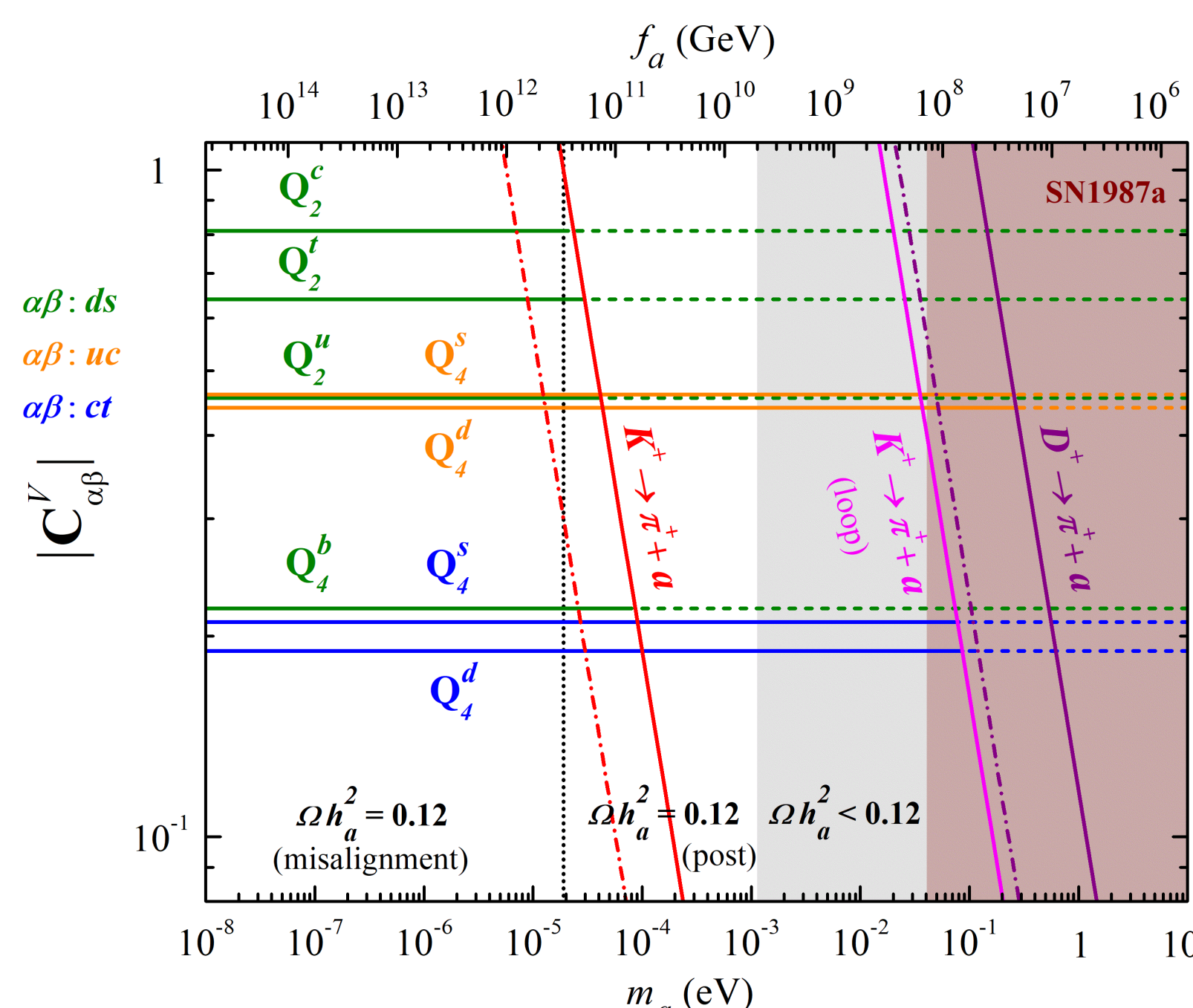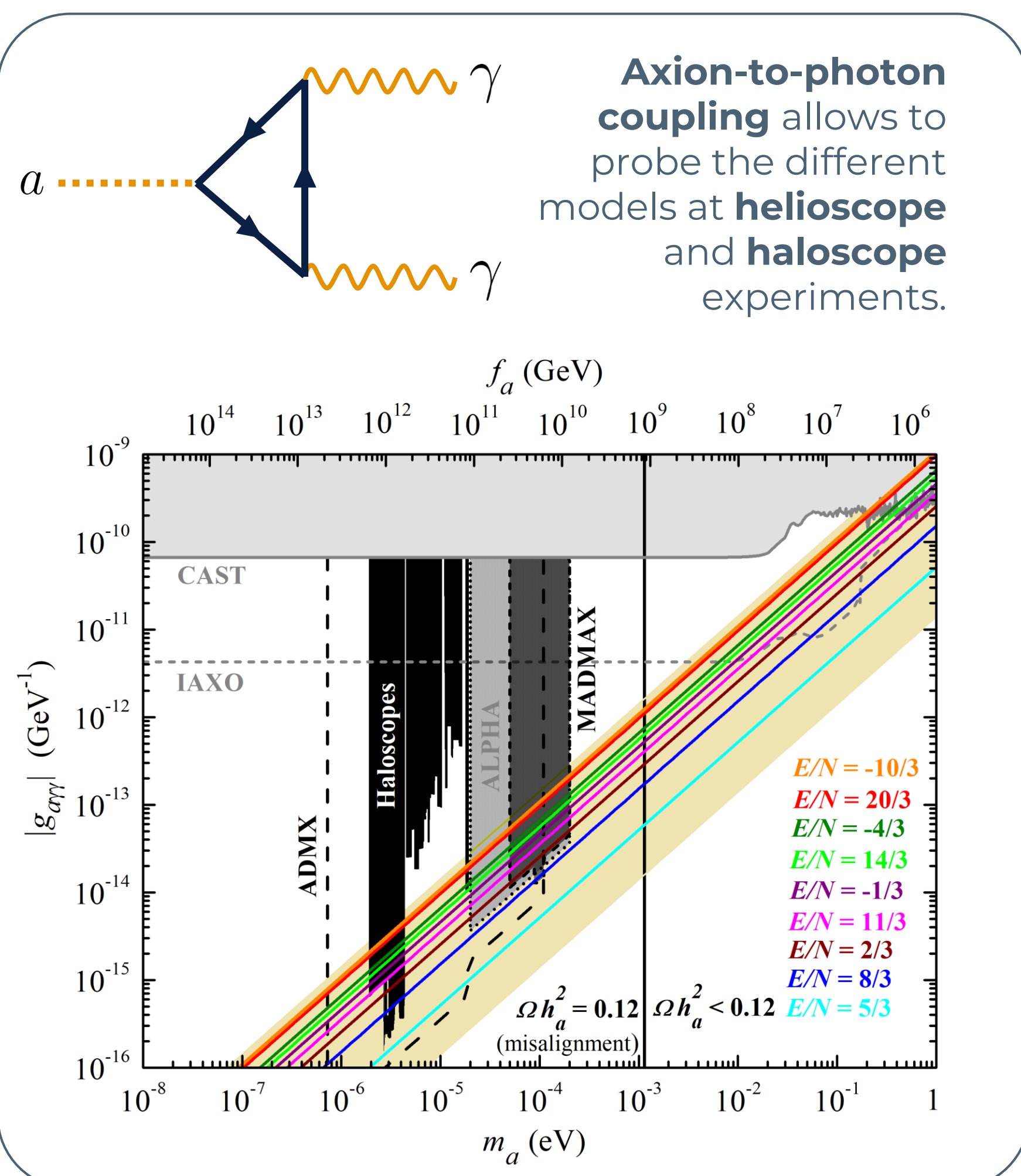
PIC1 Project:
The power of symmetry in fundamental physics

Supervisor:
Filipe Joaquim

Report

2024: MSc in Engineering Physics

MEFT

Master Thesis:
Minimal U(1) 2HDM for quark and lepton flavour

Supervisors:
Filipe Joaquim
Henrique Câmara

Thesis

Articles & Publications

- Minimal U(1) two-Higgs-doublet models for quark and lepton flavor
  J.R. Rocha, H.B. Câmara, R.G. Felipe, F.R. Joaquim
  Published in: Phys.Rev.D 110 (2024) 3, 035027

- Flavored Peccei-Quinn symmetries in the minimal νDFSZ model
  J.R. Rocha, H.B. Câmara, F.R. Joaquim
  ArXiv: 2504.00088

Some Talks at International Conferences & Schools

- **FLASY 2025: 11th Workshop on Flavour Symmetries and Consequences in Accelerators and Cosmology** (INFN ROMA TRE, Rome)

- **PLANCK 2024: THE 26TH INTERNATIONAL CONFERENCE FROM THE PLANCK SCALE TO THE ELECTROWEAK SCALE** (CFTP, Lisbon)

- **ISAPP 2024: PARTICLE CANDIDATES FOR DARK MATTER** (SGGS, Padua)

- **WORKSHOP ON MULTI-HIGGS MODELS** (CFTP, Lisbon)

- **Challenges in Theoretical Particle Physics** (CFTP, Lisbon)