Centro de Astropartículas y Física de Altas Energías
Universidad Zaragoza

Università degli Studi di Padova
Dipartimento di Fisica e Astronomia "Galileo Galilei"

Light New Physics in τ

JA, G. Levati, P. Paradisi, S. Rigolin, N. Selimovic

Saturnalia '23
December 1, 2023

Jorge Alda jorge.alda@pd.infn.it
Università degli Studi di Padova & CAPA

Light New Physics

Axion-like Particle coupled to a Peccei-Quinn current of leptons

$$\mathcal{L}_{\rm ALP} = \frac{1}{2}\partial_\mu a \partial^\mu a - \frac{1}{2} m_a^2 a^2 - \frac{1}{2f_a}\partial_\mu a j^\mu_{\rm PQ}\,;$$

$$j^\mu_{\rm PQ} = \sum_{i,j}\left(c_\ell^{ij}\bar{\ell}_i\gamma^\mu\gamma_5\ell_j + \bar{c}_\ell^{ij}\bar{\ell}_i\gamma^\mu\ell_j + c_\nu^{ij}\bar{\nu}_{\ell_i}\gamma^\mu P_L\nu_{\ell_j}\right).$$

- $m_a \in [1\,\mathrm{MeV}, 10\,\mathrm{GeV}]$, $f_a \sim 1\,\mathrm{TeV}$, flavour-universal $c^{ij} = c\delta^{ij}$.
- $g_\ell = c_\ell m_\ell / f_a$.
- After integration-by-parts and equations-of-motion

$$\mathcal{L}_{\rm ALP,int} = \sum_\ell \left(i g_\ell \bar{\ell}\gamma_5 \ell a + \frac{ig}{2\sqrt{2}m_\ell}(g_\ell - \bar{g}_\ell + g_{\nu_\ell})(\bar{\ell}\gamma^\mu P_L \nu_\ell) W^-_\mu a + \mathrm{h.c.}\right) + (V\tilde{V}a)\,.$$

- Electroweak-preserving case: $g_\ell - \bar{g}_\ell + g_{\nu_\ell} = 0$.

Light New Physics

Scalar ϕ and pseudo-scalar $\hat{\phi}$ bosons:

$$\mathcal{L}_{\text{lightNP}} \subset \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{1}{2}m_\phi^2\phi^2 + \frac{1}{2}\partial_\mu\hat{\phi}\partial^\mu\hat{\phi} - \frac{1}{2}m_{\hat{\phi}}^2\hat{\phi}^2 - \sum_\ell \bar{\ell}(k_\ell\phi + i\hat{k}_\ell\hat{\phi}\gamma_5)\ell\,.$$

For the pseudo-scalar boson, we recover the EW-preserving ALP when the couplings are hierarchical $\hat{k}_\ell = g_\ell = cm_\ell/f_a$.

Particle decays

The NP particles can decay to a pair of leptons

$$\Gamma(S \to \ell^+\ell^-) = \frac{m_S}{8\pi}|K_\ell|^2 \left(1 - \frac{4m_\ell^2}{m_S^2}\right)^{\alpha_S} ,$$

with $K_\ell = g_\ell$ and $\alpha_S = 1/2$ for $S = a$, and $K_\ell = k_\ell$ and $\alpha_S = 3/2$ for $S = \phi$.
Also decays to 2γ through a lepton loop.

ALPs with $m_a > 2m_e$ and scalars will typically decay inside the detector.