Strongly Interacting Neutrinos in K Decays.

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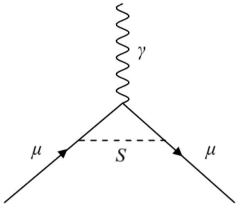
Searches for Hidden Sectors at Kaon and Hyperon Factories

Model: Dark Scalar

- A light boson S with $m_S \leq 200$ MeV, with coupling $\frac{m_\mu}{v} \sim 4 \times 10^{-4}$ solves the $(g-2)_\mu$.



$$\begin{aligned} V_{\text{portal}} &= A\,(H_u^\dagger H_d + H_d^\dagger H_u)\phi \\ &+ \left[\lambda_u H_u^\dagger H_u + \lambda_d H_d^\dagger H_d + \lambda_{ud}(H_u^\dagger H_d + H_d^\dagger H_u)\right]\phi^2 \ . \end{aligned}$$

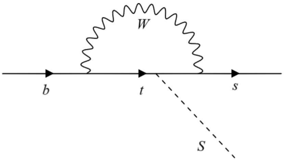
H_u and H_d get vevs, but ϕ doesn't.

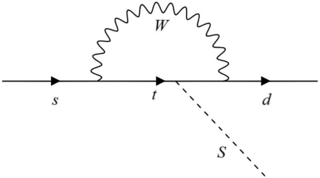
At low energy

After electroweak symmetry breaking:

$$\mathcal{L}_S = \frac{1}{2}(\partial_\mu S)^2 - \frac{1}{2} m_S^2 S^2 - \sin\theta \tan\beta \sum_{f=d,l} \frac{m_f}{v} \bar{f} f S - \sin\theta' \cot\beta \sum_{f=u} \frac{m_f}{v} \bar{f} f S,$$

No coupling to neutrinos but $b \to sS$ and $s \to dS$ are also generated.





Coupling to neutrinos (2005.08920)

If there is sterile neutrino ν_D then there is a coupling with the scalar S .

$$\mathcal{L}_S \supset \frac{1}{2}(\partial_\mu S)^2 - \frac{1}{2}m_S^2 S^2 - \eta_d \sum_{f=d,l} \frac{m_f}{v}\bar{f}fS - \eta_u \sum_{f=u}\frac{m_f}{v}\bar{f}fS - g_D S\bar{\nu}_D\nu_D .$$

$g_D \sim 1$.

The mixing between the flavor eigenstates ν_α and mass eigenstates ν_i of the four Dirac neutrinos is given by

$$\nu_{\alpha(L,R)} = \sum_{i=1}^{4} U_{\alpha i}^{(L,R)} \nu_{i(L,R)} \ , \quad (\alpha = e, \mu, \tau, D) \, , \tag{1}$$

Note with Z' the coupling is $Z'_\mu \bar{\nu}_D \gamma^\mu \nu_D = Z'_\mu \left[\bar{\nu}_{DL}\gamma^\mu \nu_{DL} + \bar{\nu}_{DR}\gamma^\mu \nu_{DR}\right]$.

S Decays

The decay width of S to all three light neutrinos $(\nu_i,\ i = 1, 2, 3)$ is

$$\Gamma_{S \to \nu\nu} = \frac{g_D^2}{8\pi}(1 - |U_{D4}|^2)^2 m_S \,, \tag{2}$$

and its decay width to e^+e^- is given by

$$\Gamma_{S \to e^+e^-} = \frac{\eta_d^2}{8\pi} \frac{m_e^2 m_S}{v^2} \left(1 - 4\frac{m_e^2}{m_S^2}\right)^{3/2} . \tag{3}$$

If $L \sim -\frac{1}{4}\kappa S F_{\mu\nu} F^{\mu\nu}$ then $S \to \gamma\gamma$ is also possible .

Phenomenology

- If $m_{\nu_4} > m_S$, The decay width of ν_4 to $S\nu$ (with ν denoting all three light neutrinos) is

$$\Gamma_{\nu_4 \to S\,\nu} = \frac{g_D^2}{8\pi}|U_{D4}|^2\left(1-|U_{D4}|^2\right)\left(1-\frac{m_S^2}{m_{\nu_4}^2}\right)^2 m_{\nu_4}\,.$$

- ν_4 may be created in neutrino scattering or semi leptonic decays: e.g $K^+ \to \ell\bar{\nu}_4 \to \ell\bar{\nu}S$ with S decaying to visible final states.

- S emitted from ν through an effective $g_{eff}\bar{\nu}\nu$ interaction: So the signal in semi leptonic decay is $K^+ \to \ell\bar{\nu} \to \ell\bar{\nu}S$. g_{eff} can be constrained from neutrino self interaction.

- The BR for decay $K^+ \to \mu\bar{\nu}S$ with S emitted from the $\mu \sim 10^{-14}$, 1908.08625