PROCEEDINGS OF SCIENCE

A simple solution to the LSND, MiniBooNE and muon $g-2$ anomalies

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In a simple extension of the Standard Model (SM) with a second Higgs doublet and a dark singlet scalar, we are able to: (i) explain the MiniBooNE (MB) and Liquid Scintillator Neutrino Detector (LSND) anomalies while remaining compatible with the KARMEN null result, (ii) in the process, obtain a portal to the dark sector, and (iii) account comfortably for the observed value of $(g-2)_\mu$. Three SM singlet neutrinos allow for explaining non-zero neutrino masses via a seesaw Type-I mechanism, with the lighter two states participating in the LSND and MB interactions.

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1. Introduction

The SM has provided a reliable framework in particle physics, which has been amply verified in both collider and non-collider experiments. In the latter category, however, two long-standing anomalous results which have large statistical significance are: (i) excesses in electron-like events in short baseline neutrino experiments, in particular, the LSND [1] and MB [2] excesses, and (ii) observed discrepancy in the muon anomalous magnetic moment value, $(g-2)_\mu$ [3]. Assuming that these discrepancies are due to new physics, as opposed to un-understood SM backgrounds or detector-specific effects, we show that the addition of a second Higgs doublet, acting as a portal to the dark sector, provides an understanding of all three discrepant results mentioned above.

2. The model: 2HDM + a singlet scalar (dark sector)

In this model, the SM particle content has been extended by: (i) a second Higgs doublet, ϕ_H, in addition to the SM one, ϕ_h, (ii) a singlet real scalar, $\phi_{h'}$, and (iii) three singlet neutrinos, ν_{R_i}. In the Higgs basis $(\phi_h, \phi_H, \phi_{h'})$ [4] the relevant Lagrangian is as follows [5]:

$$\begin{aligned}\mathcal{L} &= \sqrt{2}\Big[(X^u_{ij}\tilde{\phi}_h+\bar{X}^u_{ij}\tilde{\phi}_H)\bar{Q}^i_L u^j_R + (X^d_{ij}\phi_h+\bar{X}^d_{ij}\phi_H)\bar{Q}^i_L d^j_R + (X^e_{ij}\phi_h + \bar{X}^e_{ij}\phi_H)\bar{L}^i_L e^j_R \\ &+ (X^\nu_{ij}\tilde{\phi}_h + \bar{X}^\nu_{ij}\tilde{\phi}_H)\bar{L}^i_L \nu_{R_j} + \frac{1}{\sqrt{8}} m_{ij}\bar{\nu}^c_{R_i}\nu_{R_j} + \lambda^N_{ij}\bar{\nu}^c_{R_i}\phi_{h'}\nu_{R_j} + h.c.\Big]. \qquad (1)\end{aligned}$$

The fermion masses, m_f, receive contributions only from X^f_{ij}, since $\langle\phi_H\rangle = 0 = \langle\phi_{h'}\rangle$ while $\langle\phi_h\rangle = v \simeq 246\,\text{GeV}$. Consequently, $\bar{X}^f$ are non-diagonal matrices and independent of X^f. That is, the off-diagonal couplings of the additional scalars to quarks are free parameters and can be very tiny, which help us stay safe from several existing bounds, notably from (i) CHARM II and MINERvA, (ii) the T2K near detector, ND280 and (iii) NC ν-nucleon scattering at high energies.

3. Explaining the LSND, MB and $(g-2)_\mu$ anomalies

After rotation the coupling strengths of the scalars h, h', H (mass eigenstates) with fermions, respectively, are

$$y^h_f = m_f/v, \quad y^{h'}_f = y^f\,\sin\delta, \quad y^H_f = y^f\,\cos\delta, \qquad (2)$$

where δ is the scalar mixing angle between the mass and gauge eigenstates. Both h' and H have one-loop contribution to $(g-2)_\mu$, Δa_μ, as shown in Fig. 1 (left panel). The H contribution Δa^H_μ is significantly larger while $\Delta a^{h'}_\mu \simeq 17\%$ of the total, as shown in Fig. 1 (right panel).

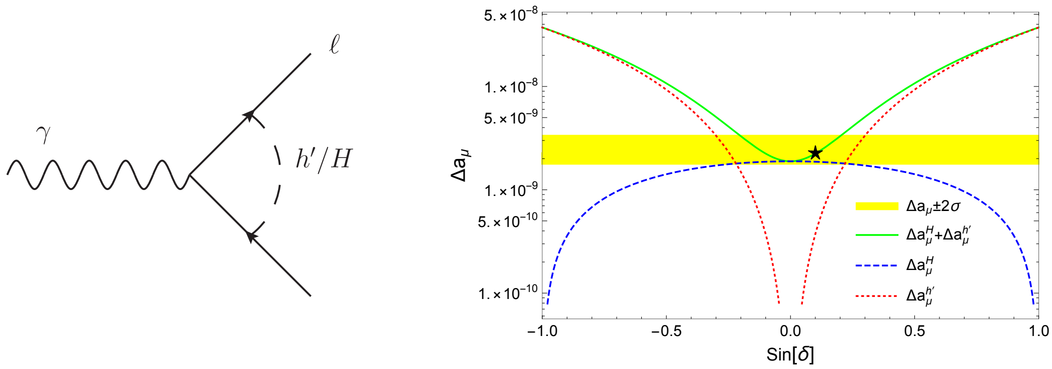

Figure 1: The light scalars (H, h') contributions to $(g-2)_\mu$ using the benchmark point shown in Table 1.

m_{N_1}	m_{N_2}	m_{N_3}	$y_u^{h'(H)} \times 10^6$	$y_{e(\mu)}^{h'} \times 10^4$	$y_{e(\mu)}^{H} \times 10^4$
85 MeV	130 MeV	10 GeV	0.8(8)	0.23(1.6)	2.29(15.9)
$m_{h'}$	m_H	$\sin\delta$	$y_d^{h'(H)} \times 10^6$	$y_{\nu_{i2}}^{h'(H)} \times 10^3$	$\lambda_{12}^n \times 10^2$
17 MeV	750 MeV	0.1	0.8(8)	1.25(12.4)	7.5

Table 1: Benchmark point used for calculating $(g-2)_\mu$ and for LSND, MB event generation.

The relevant Lagrangian specifying neutrino interactions with the light scalars h', H is given by

$$\mathcal{L}_\nu^{\rm int} \simeq y^{\phi}_{\nu_{ij}} \bar{\nu}_i N_j\, \phi + \lambda^n_{ij} (\cos\delta\, h' - \sin\delta\, H) \bar{N}_i N_j + h.c.$$

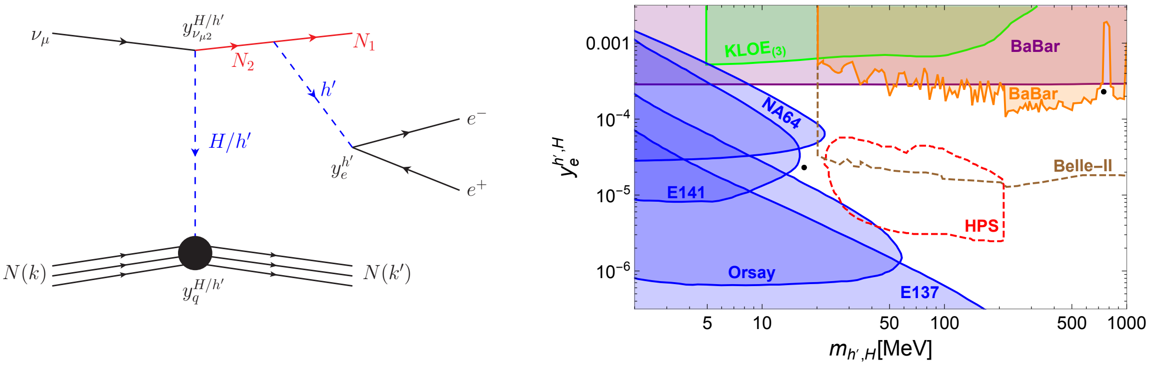

Figure 2: Left panel: Feynman diagram of the process contributes to the LSND and MB excesses. Right panel: Relevant constraints on our model, see Fig. 9 in Ref. [6] for details.

The number of events in MB and LSND through the process shown in Fig. 2 (left panel) is given by [5]

$$\mathrm{N_{events}} = \eta \int dE_\nu dE_{N_2} \frac{d\Phi^\nu}{dE_\nu} \frac{d\sigma}{dE_{N_2}} \times \mathrm{BR}(N_2 \to N_1 h'), \tag{3}$$

where Φ^ν is the flux of incoming muon neutrino and η contains all detector related information. Here, $d\sigma/dE_{N_2}$ is the total differential cross section for the target (CH_2) in MB and LSND.

From Fig. 3, it is clearly seen that very good fits to the data of both MB and LSND are obtained for the energy and angular distributions. In this figure, the blue bands in the top panels refer to a 15% systematic uncertainty. Now, we discuss below several points are relevant to understanding the results obtained.

1. In our scenario, all LSND events stem from their decay-in-flight (DIF) flux at high energies, which are kinematically allowed to produce the heavy particle N_2.

2. In MB, both H, h' contribute to the total number of events. The h' contribution is very small ($\sim$ 10%) comparing with the H contribution. In particular, the h' coherent contribution helps sufficiently populate the most forward bin in the angular distribution.

3. Consequently, due to the N_2 production as a heavy particle ($m_{N_2} \simeq 130$ MeV) is necessary, our model is compatible with the null result from KARMEN, which has a narrow-band DIF flux that peaks at ~ 30 MeV.

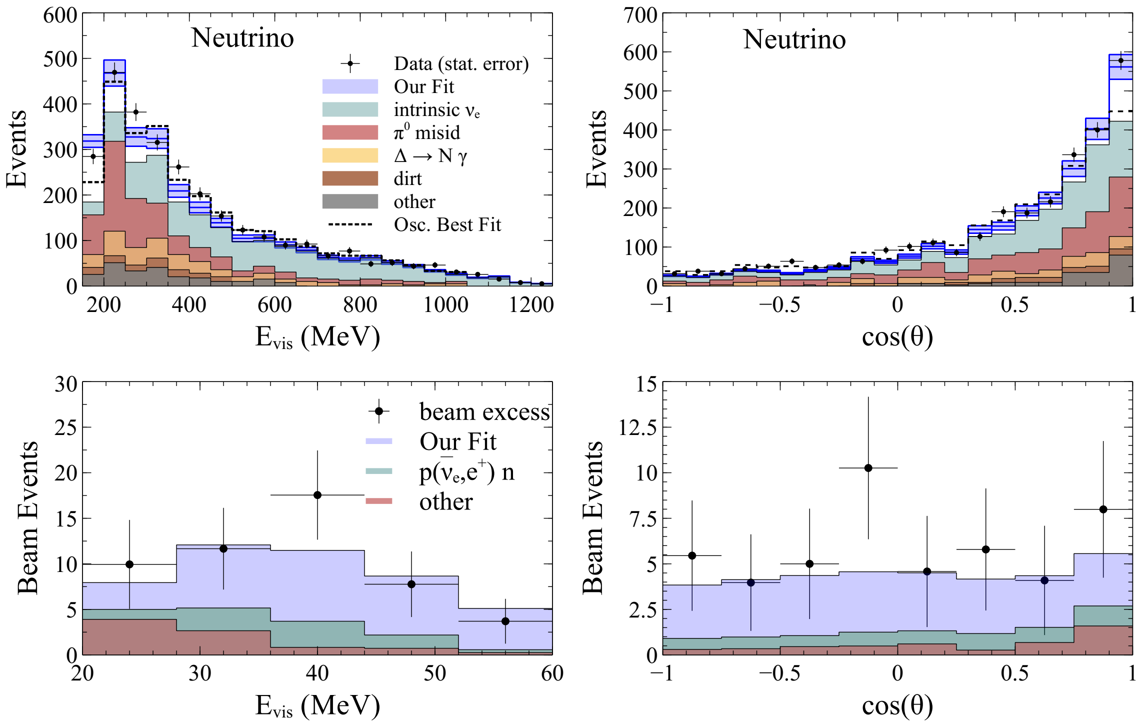

Figure 3: The energy and angular distributions of the MB data (top panels) [2] and the LSND data (bottom panels) [1] along with our fits using the benchmark point shown in Table 1.

4. Conclusion

In the present work, we have obtained a non-oscillation, new physics explanation for both LSND and MB. In addition, the expanded scalar sector allows us to obtain a portal to the dark sector and account comfortably for the observed value of $(g-2)_\mu$. Three singlet neutrinos allow for generating non-zero neutrino masses via a seesaw Type I mechanism, with two of them participating in the LSND and MB interactions. Of the sub-GeV scalars in our model, H can be searched for in Belle-II, as shown in Fig. 2 (right panel). For h', there is an existing/interesting experimental hint (see Fig. 11 in Ref. [7]) which is a significant excess detected by the T2K ND280 detector in the $10-20$ MeV invariant mass-bin of electron-like FGD1-TPC pairs.

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