GeV scale neutrinos: meson interactions and DUNE sensitivity

HIDDeN

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The existence of right handed neutrinos (or heavy neutral leptons, HNLs) is the most natural extension of the SM to account for the measured neutrino masses and mixings. Flavor eigenstates will now have a heavy component:

$$\nu_\alpha = \sum_{i=1}^{3} U_{\alpha i}\nu_i + \sum_{i=4}^{3+n} U_{\alpha i}N_i \equiv \sum_i U_{\alpha i} n_i$$

In the minimal scenario, no extra interactions are added to the SM, and its particle content is only enlarged with right-handed neutrinos. Their interactions will only be controlled by their masses and mixings with light states. HNLs may live at very different energy scales.

Why the GeV scale?

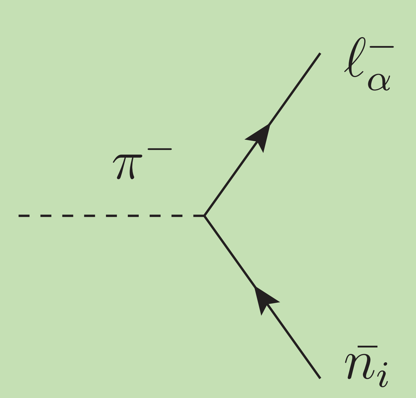
- No extra Higgs hierarchy problem, in opposition to the type-I seesaw with GUT scale neutrinos
- Feasible solution of the BAU via leptogenesis[1-3]
- Experimentally accesible in lab experiments: peak searches, beam dumps, colliders...

[1]JHEP 08 (2016) 157 [1606.06719]
[2]JHEP 01 (2019) 164 [1810.12463]
[3]JHEP 07 (2019) 078 [1905.08814]

Meson interactions

At low energies, meson interactions play an important role in HNL phenomenology. We compute the relevant low-energy effective operators, integrating out the weak bosons and introducing the hadronic matrix elements.

Pseudoscalars*

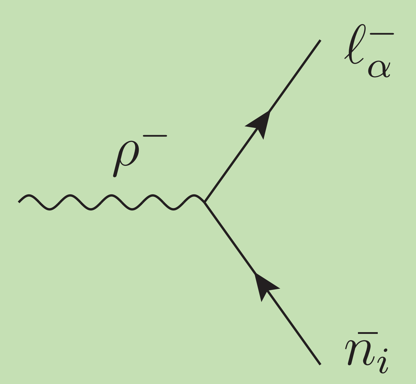


Momentum acting as derivative

$$\langle 0 | j^A_{a,\mu} | P_b \rangle = i\delta_{ab}\frac{f_P}{\sqrt{2}}p_\mu$$

$$\mathcal{O}_{\pi\ell_\alpha\bar{n}_i} = i\sqrt{2}G_F U_{\alpha i}V_{ud}f_\pi \bar{\ell}_\alpha(m_\alpha P_L - m_i P_R)n_i\pi^- + \text{h.c.}$$

Vectors*

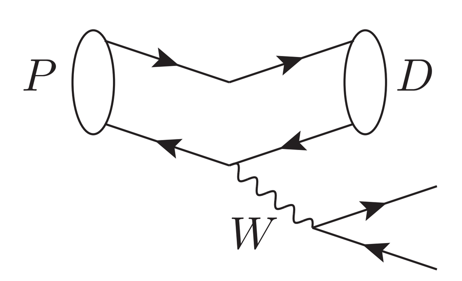


Polarization: no derivative

$$\langle 0 | j^V_{a,\mu} | V_b \rangle = \delta_{ab}\frac{f_V}{\sqrt{2}}\epsilon_\mu$$

$$\mathcal{O}_{\rho\ell_\alpha\bar{n}_i} = -\sqrt{2}G_F U_{\alpha i}V_{ud}f_\rho \rho^-_\mu(\bar{\ell}_\alpha\gamma^\mu P_L n_i) + \text{h.c.}$$

Semileptonic meson decays



Form factors[4,5]

$$\left\langle D | j^V_{W,\mu} | P \right\rangle = \frac{1}{2}V_{qq'}\left(p_\mu f_+(q^2) + q_\mu f_-(q^2)\right)$$

$$\mathcal{O}_{PD\ell_\alpha\bar{n}_i} = -i\sqrt{2}G_F V_{qq'}U_{\alpha i}\left[2f_+(q^2)\bar{\ell}_\alpha\gamma^\mu P_L n_i\left(\partial_\mu\phi_D\right)\phi_P^\dagger + \left(f_+(q^2) - f_-(q^2)\right)\partial_\mu(\bar{\ell}_\alpha\gamma^\mu P_L n_i)\phi_D\phi_P^\dagger\right] + \text{h.c.}$$

FeynRules[6] implementation

- ✓ Extended neutrino sector in a a 3+1 scenario: one extra state and enlarged mixing matrix.
- ✓ Inclusion of mesons up to 2 GeV: $\pi, K, \rho, K^*, \eta, \eta', \omega, \phi, D, D_s$
- ✓ HNLs involved in effective meson interactions as well as purely leptonic processes

Efficient event generation in MadGraph5[7]

*Very similar results for neutral mesons

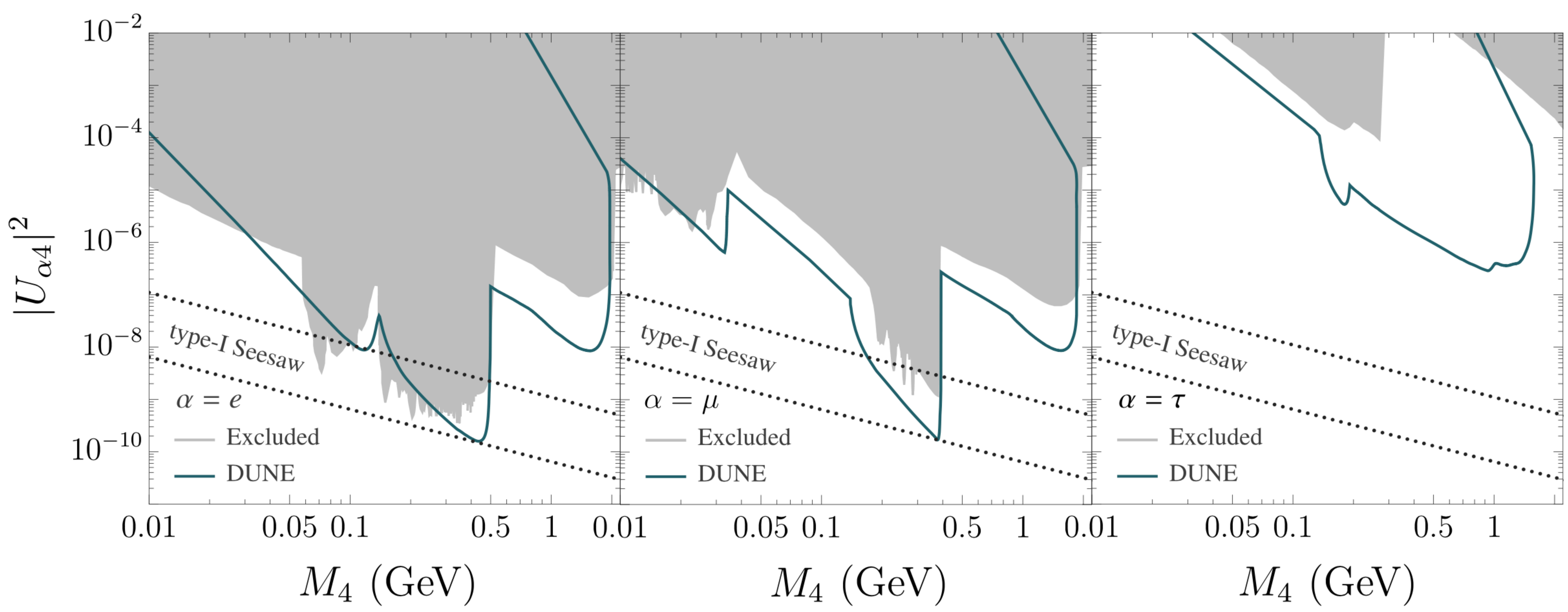
[4]Phys. Rev. D96 (2017) 054514 [1706.03017]
[5]2nd DAPHNE Physics Handbook:315-389, pp. 315 - 389, 1994 [hep-ph/9411311]
[6]Comput. Phys. Commun. 185 (2014) 2250 [1310.1921]
[7]JHEP 07 (2014) 079 [1405.0301]

DUNE Near Detector sensitivity

Protons on target → Charged mesons → HNLs → Visible decays in ND

- 90% C.L.
- $7.7 \cdot 10^{21}$ protons on target
- No background assumed
- 20% signal efficiency[8]

Most bounds are improved!!!



[8]Phys. Rev. D100 (2019) 052006 [1902.07598]

CONCLUSIONS

Heavy neutrinos in the GeV range are a simple and testable solution for several SM problems. They can be produced and decay in meson interactions, which we have derived and implemented in FeynRules. As an application, we have estimated the sensitivity of the DUNE ND to heavy neutrinos, finding its potential to probe very small mixings and improve most current bounds.