Heavy Sterile Neutrino Decay at Short-Baseline Experiments

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Introduction

We studied a neutrino decay scenario as a potential solution to conciliate the tension between appearance and disappearance data at the short-baseline experiments. Particularly, we considered a heavy neutrino mass-eigenstate that decays into a usual light neutrino plus a massless scalar. Under this neutrino decay hypothesis and assuming Dirac or Majorana neutrinos,

- we fitted **LSND** and **MiniBooNE** electron neutrino appearance datax;
- we included the short-baseline null-result obtained by **KARMEN** experiment;
- we estimated the constraint to **MINOS** ν_μ disappearance data, assuming that decay effects on MINOS analysis is very small;
- we tested the future **SBN** program sensitivity to the electron neutrino appearance channel.

Neutrino decay scenario

We introduce a new interaction that allows ν_4, with mass m_4, to decay into a new, very light scalar field ϕ and a ν_e. We are going to explore ν_e appearance and ν_μ disappearance channels (plus antineutrinos) in short-baseline experiments. We are going to work with two cases: Majorana and Dirac neutrinos. The summary of the phenomenology is available in the following tables:

Dirac	**Majorana**
$\mathcal{L}_{\rm Dirac} = -g_{\rm D}\bar{\nu}_4 \frac{(1-\gamma_5)}{2}\nu_e\phi + H.c.$	$\mathcal{L}_{\rm Majorana} = -g_{\rm M}\bar{\nu}_4\nu_e\phi + H.c.$
Decay channels:	
$P_{\mu e}(P_{\bar{\mu}\bar{e}}), P_{\mu\mu}(P_{\bar{\mu}\bar{\mu}})$	$P_{\mu e}(P_{\bar{\mu}\bar{e}}), P_{\mu\bar{e}}(P_{\bar{\mu} e}), P_{\mu\mu}(P_{\bar{\mu}\bar{\mu}})$
$B_e = 1, B_{\bar{e}} = 0$ $\Gamma_{4e} = \lvert g_{\rm D}\rvert^2\, m_4^2\,/\,32\pi E_4$	$B_e = 0.5, B_{\bar{e}} = 0.5$ $\Gamma_{4e} = \lvert g_{\rm M}\rvert^2\, m_4^2\,/\,16\pi E_4$

Conversion Probabilities:

$$P_{\mu e} = P_{\bar{\mu}\,\bar{e}} = W_1(E_e, E_4)B_e|U_{\mu 4}|^2(1-e^{-\Gamma_{4e}L})$$

$$P_{\mu\bar{e}} = P_{\bar{\mu}\,e} = W_2(E_e, E_4)B_{\bar{e}}|U_{\mu 4}|^2(1-e^{-\Gamma_{4e}L})$$

Survival Probability:

$$P_{\mu\mu} = P_{\bar{\mu}\bar{\mu}} = (1-|U_{\mu 4}|^2)^2 + (|U_{\mu 4}|^2)^2 e^{-\Gamma_{4e}L}$$

$$W_1(E_e, E_4) = 2E_e/E_4^2$$

$$W_2(E_e, E_4) = 2(E_4 - E_e)/E_4^2$$

where $g_{\rm D}$ (Dirac) and $g_{\rm M}$ (Majorana) are the coupling constants of the new interaction, $|U_{\mu 4}|^2$ is related with the quantity of ν_μ presented in ν_4, L is the baseline, E_e and E_4 are, respectively, the energies of produced $\nu_e(\bar{\nu}_e)$ and initial ν_4 and Γ_{4e} is the decay width of the considered process.

Results: Analysis under decay scenario

To do the analysis, we simulated neutrino event rates under decay scenario using GLoBES software for LSND, MiniBooNE and KARMEN experiments. We fitted our simulated events with the available ν_e appearance data. MINOS constraint was estimated with its ν_μ disappearance data. Details of the full simulation and analysis are available on Ref. [1]. The results of χ^2 analysis are available on the following table and plots.

Experiment (app/disapp)	ν nature	$\chi^2_{\rm min}$/dof	Best-fit $(\lvert U_{\mu 4}\rvert^2, gm_4)$
LSND+MiniBooNE (app)	Dirac	45.33/31	(0.063, 1.17 eV)
LSND+MiniBooNE (app)	Majorana	48.34/31	(0.21, 0.54 eV)
KARMEN (app)	Dirac/Majorana	6.47/7	No positive signal
All+MINOS (app+disapp)	Dirac	56.42/40	(0.0086, 3.41 eV)
All+MINOS (app+disapp)	Majorana	58.45/40	(0.0086, 2.93 eV)

Note: we take MINOS constraint from the ν_μ disappearance data to be $|U_{\mu 4}|^2 < 2.3\times 10^{-2}$ at the 90% C.L. for all values of gm_4 of interest. To include MINOS in the combined analysis, we add an penalty factor of $\chi^2_{\rm penalty} = 4.6\,(|U_{\mu 4}|^2/2.3\times 10^{-2})^2$ to describe the MINOS constraint.

Reference

[1] André de Gouvêa, O.L.G. Peres, Suprabh Prakash, and G.V. Stenico. On The Decaying-Sterile Neutrino Solution to the Electron (Anti)Neutrino Appearance Anomalies. 11 2019.

Results: Allowed, excluded and sensitivity regions

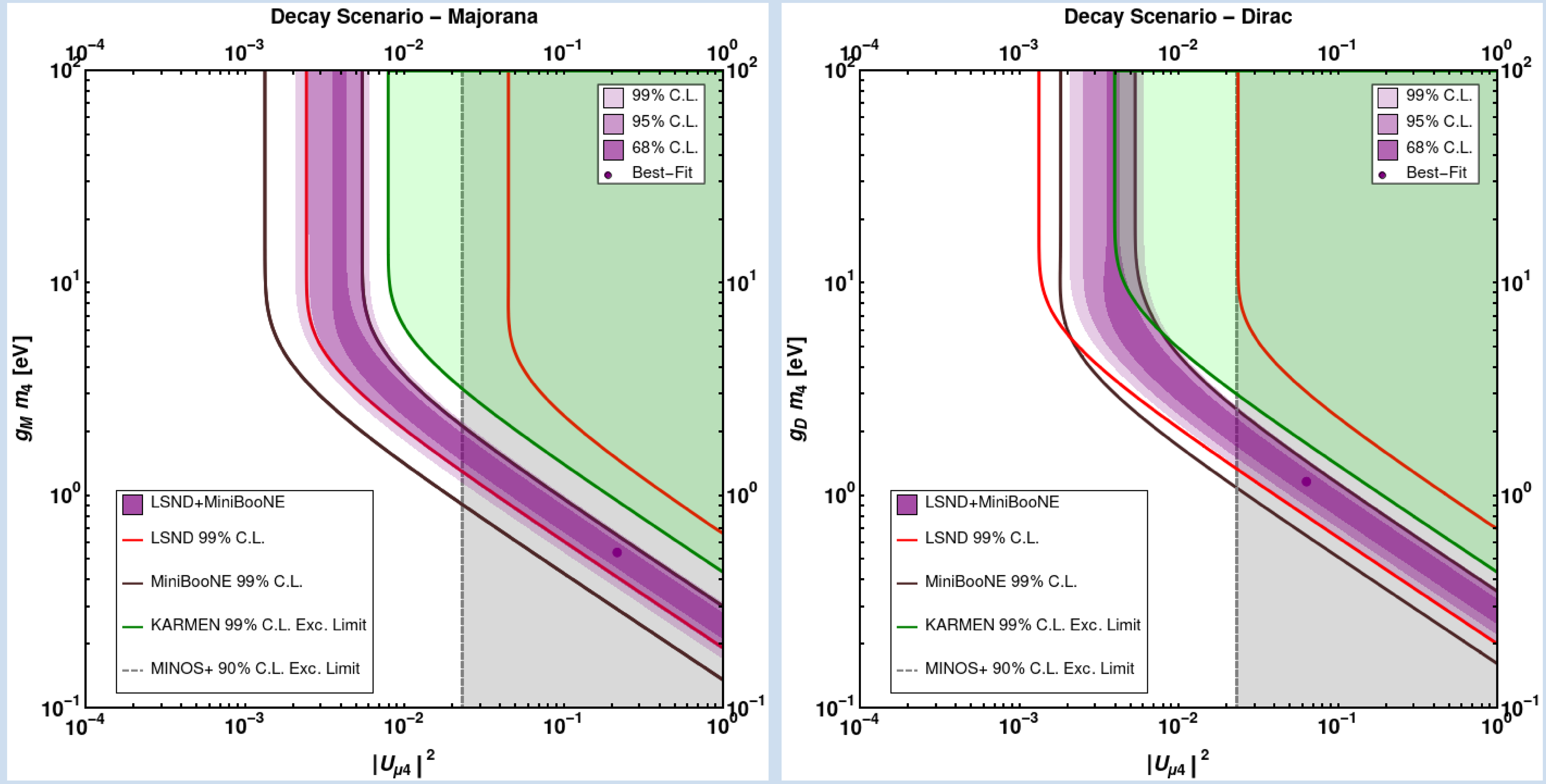

Figure 1: *Allowed regions of the $(|U_{\mu 4}|^2, gm_4)$ parameter space when the decaying-sterile-neutrino hypothesis is matched against the combined LSND and MiniBooNE data. The region to the right of the vertical line is excluded by MINOS and the green shaded region on the top-right of the green line is excluded by KARMEN.*

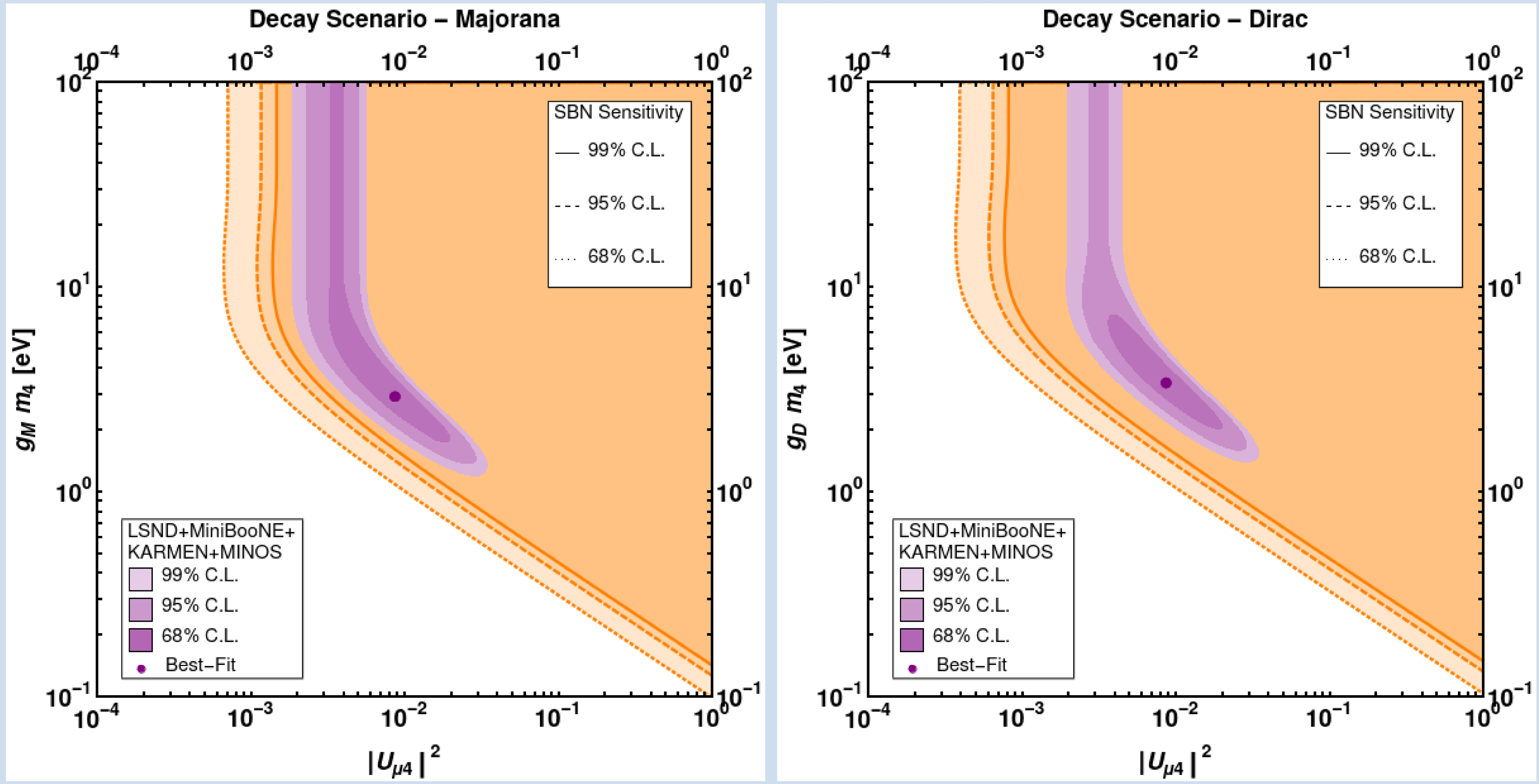

Figure 2: *Allowed regions (shades of purple) of the $(|U_{\mu 4}|^2, gm_4)$ parameter space when the decaying-sterile-neutrino hypothesis is matched against the combined LSND, MiniBooNE and KARMEN data and MINOS constrains. In the same context, the orange regions indicate the sensitivity of the SBN Program for Majorana (left) and Dirac neutrinos (right).*

In view of the results under the neutrino decay hypothesis, we obtained reasonable fits for the considered short-baseline data and for both Majorana and Dirac cases. The SBN sensitivity analysis showed that the future experiment has the potential to definitively test the decay hypothesis.

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