Snowmass 2021 Letter of Interest
Neutrino Decay as a Solution to the Short-Baseline Anomalies

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(Dated: August 31, 2020)

Most of the available data obtained in neutrino experiments - which measure neutrinos from the sun, the atmosphere, reactor and accelerator sources - can be accommodated through flavor oscillation among the three active neutrinos. To enable such oscillatory behavior, the neutrino flavor states are required to be non-trivially mixed with three distinct neutrino mass states [1]. The model, known as the *standard three-neutrino oscillation*, has two independent squared-mass differences that rule the oscillation frequency, as well as the distance traveled by the neutrino (baseline) and its energy. A summary of the best-fit values for the three neutrino model parameters can be found in the global analysis performed in Ref. [2].

Short-Baseline Anomalies. The so-called short-baseline anomalies are a set of experimental results that cannot be fitted by the *standard three-neutrino oscillation* scenario. This is about L/E, not only L. What about the following. Standard neutrino oscillations should develop when the oscillation phase

$$1.27\frac{(\Delta m^2_{ij}/\mathrm{eV}^2)(L/\mathrm{m})}{(E/\mathrm{MeV})} \sim \mathcal{O}(1), \tag{.1}$$

where the two standard mass squared splittings have been measured to be $\Delta m^2_{21} \simeq 7.5 \times 10^{-5}$ eV^2 and $|\Delta m^2_{31}| \simeq 2.5 \times 10^{-3}$ eV^2. Nevertheless, a number of experimental results are consistent with a much larger value of the mass splitting of 1 eV^2 or larger. These are the following:

1. the positive signal of electron (anti)neutrino candidates in the LSND [3] and MiniBooNE [4–6] experiments;
2. the deficit of detected electron neutrinos in Gallium-based experiments if compared to the expectation by calibrating these experiments with radioactive sources [7, 8];
3. the deficit of detected electron antineutrinos in reactor experiments if compared to the expectation considering the evaluation of the neutrino flux at nuclear reactors [9].

In the context of neutrino oscillation, a way to address these unexpected results is to add an extra neutrino state that could participate in oscillations, but without weak interactions, i.e. a sterile neutrino. This addition allows a new, larger oscillation frequency to induce flavor transition in both appearance and disappearance channels in short-baseline experiments. In this kind of model (dubbed $3+1$ model), the anomalous results may be explained in terms of muon (anti)neutrino conversion to electron (anti)neutrino - explaining the excess of events observed in LSND and MiniBooNE - and the electron (anti)neutrino disappearance - accounting for the Gallium and reactor anomalies. For recent summaries of the 3+1 fit of these data, see, for example, Refs. [10–13].

However, in the $3+1$ model, the presence of $\nu_\mu \to \nu_e$ appearance at short baselines implies both nonzero electron and muon neutrino disappearance. It turns out that muon disappearance measurements pose severe constraints on this interpretation of the short baseline anomalies, in particular the data from MINOS/MINOS+ [14], IceCube [15] and the Super-Kamiokande [16, 17] experiments. This leads to a strong tension between appearance and disappearance measurements in the $3+1$ framework [11]. In view of this, it is crucial to investigate alternative solutions to the short baseline anomalies, such as production and decay of heavier neutrino species.

Neutrino Decay. Neutrino decay models appear as a solution to conciliate the tension among appearance and disappearance data, while presenting a venue to explain the short baseline anomalies. Some neutrino decay models were applied in the context of short-baseline anomalies and they will be pointed out here:

- A heavy fourth neutrino mass eigenstate that decays into an electron-type neutrino and a new massless scalar particle. The analyses was done first for LSND [18] and extended to MiniBooNE and KARMEN experiments. MINOS/MINOS+ constraints were included and the sensitivity for SBN program was estimated [19];
- Considering the sterile neutrino unstable in 3+1 scenario provides a better fit than in the usual 3+1 one. The analysis was done by combining the short-baseline neutrino data with IceCube experiment [20];
- A sterile neutrino with a mass around one keV that decays into active neutrinos plus a new light boson. The analysis was done for MiniBooNE experiment. Constraints from null-oscillation results, direct neutrino mass measurements and cosmological bounds were included [21] (see also Ref. [22]);
- A sterile neutrino decaying into a photon and a light neutrino. The analysis was done for MiniBooNE experiment [23]. Other radiative sterile-neutrino decays were also explored as a potential explanation to the observations reported by LSND and MiniBooNE [24–27].

The outlook of this letter is to encourage neutrino decay studies. Similarly to 3+1 models, many neutrino decay models can accommodate the short-baseline anomalies and at the same time alleviate the tension between appearance and disappearance data. A final goal would be to perform a global analysis of the neutrino decay framework, including constraints from existing experiments and cosmology, as well as sensitivity studies for future experiments.

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