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Keep it Simple: Simplified Frameworks for Long-Lived Particles at Neutrino Facilities

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Modern-day accelerator neutrino facilities are excellent venues for searches for new-physics particles. Many distinct new-physics models predict overlapping signatures and phenomenology in these experiments. In this work, we advocate for the adoption of simplified frameworks when studying these types of new-physics signatures, which are characterized by a small number of primary variables, including particle masses, lifetimes, and production and decay modes/rates that most directly control signal event rates and kinematics. In particular, taking the example of long-lived particles that decay inside a neutrino detector as a test case, we study formulate and study simplified frameworks in the context of light scalars/fermions produced in kaon decays which then decay into final states containing an electron-positron pair. We show that using these simplified frameworks can allow for individual experimental analyses to be applicable to a wide variety of specific model scenarios. As a side benefit, we demonstrate that using this approach can allow for the T2K collaboration, by reinterpreting its search for Heavy Neutral Leptons, to be capable of setting world-leading limits on the Higgs-Portal Scalar model. Furthermore, we argue the simplified framework interpretation can serve as a bridge to model identification in the hopeful detection of a new-physics signal. As an illustration, we perform a first determination of the likelihood that, in the presence of a new-physics signal in a detector like the DUNE ND-GAr, multiple different new-physics hypotheses (such as the Higgs-Portal Scalar and Heavy Neutral Lepton ones) can be disentangled. We demonstrate that this model discrimination is favorable for some portions of detectable new-physics parameter space but for others, it is more challenging.

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