Constraining neutrino transition magnetic moments at DUNE

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Abstract

Here I present work done in collaboration with Thomas Schwetz and Jing-Yu Zhu [arXiv:2105.09699]. We consider the sensitivity of the DUNE experiment to a heavy neutral lepton, HNL (also known as sterile neutrino) in the mass range from a few MeV to a few GeV, interacting with the Standard Model via a transition magnetic moment to the active neutrinos, the so-called dipole portal. The HNL is produced via the up-scattering of active neutrinos, and the subsequent decay inside the detector provides a single-photon signal. We show that the tau-neutrino dipole portal can be efficiently probed at the DUNE far detector, using the tau-neutrino flux generated by neutrino oscillations, while the near detector provides better sensitivity to the electron- and muon-neutrino dipole portal. DUNE will be able to explore large regions of currently unconstrained parameter space and has comparable sensitivity to other planned dedicated experiments, such as SHiP.

1. Introduction

We consider the neutrino dipole portal, where a SM neutrino ν_α couples to a fourth heavy state ν_4 via a transition magnetic moment: eq. (1). It is difficult to test the d_τ transition moment, since it is hard to produce an intense ν_τ flux. Therefore, we considered the neutrino oscillations $\nu_\mu \to \nu_\tau$ at DUNE. These ν_τ may up-scatter on nuclei, nucleons or electrons via the dipole interaction in eq. (1). The heavy neutrino can travel over macroscopic distances and decay back into a light neutrino and a photon inside the detector (fig. 1). Due to the sizeable ν_μ and ν_e beam fluxes, the active-sterile transition moments d_μ and d_e can also be probed at the near detector.

$$\mathcal{L} = d_\alpha \bar{\nu}_{\alpha L}\sigma^{\mu\nu}\nu_4 F_{\mu\nu} + \text{h.c.} \qquad (1)$$

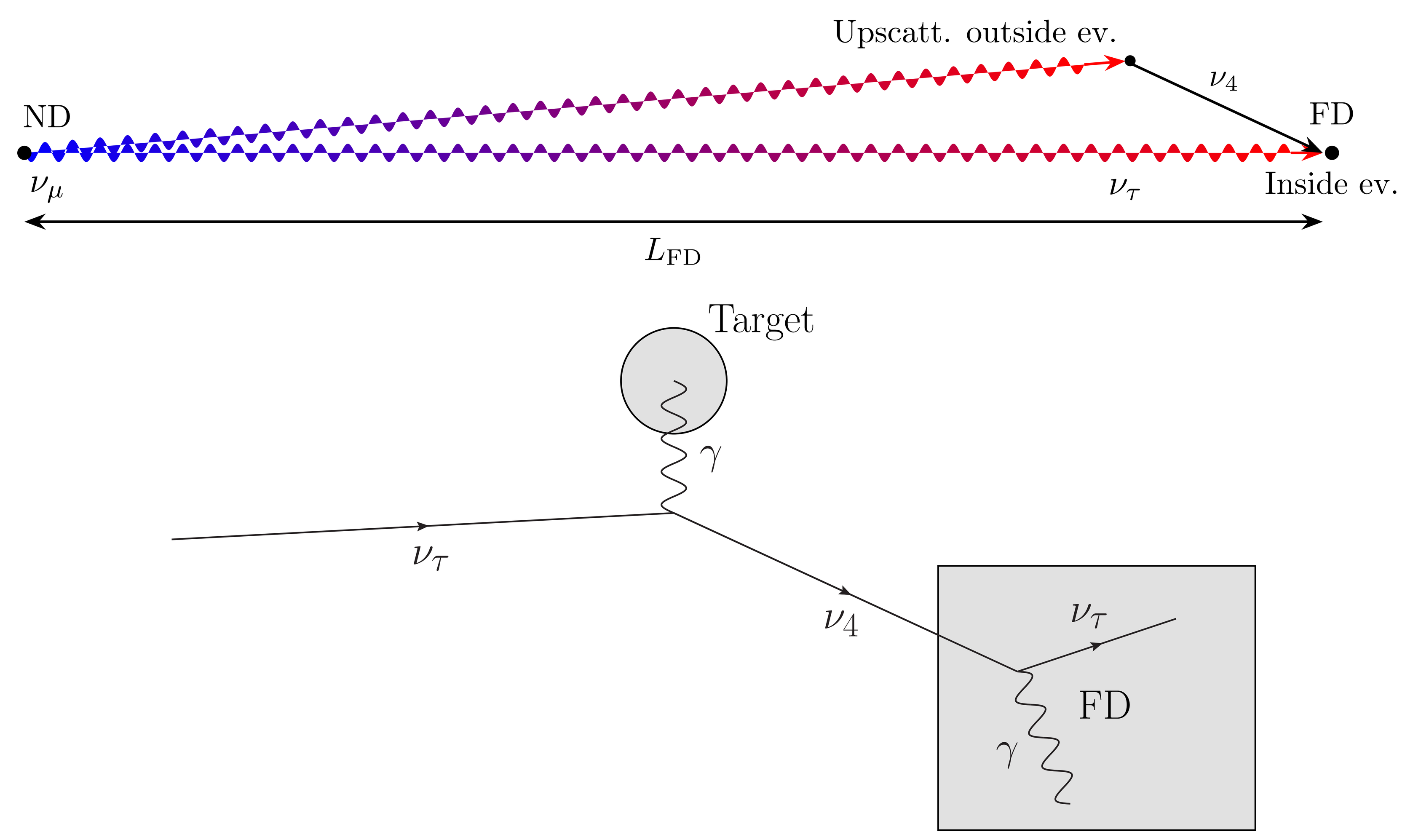

Figure 1: Cartoons of the up-scattering production and decay signal for d_τ in the far detector.

2. Signal

- **Outside events:** Up-scattering occurs in the Earth; the signature is a single-photon event. [Equation (2)]
- **Inside events, coherent:** The coherent scattering on the nucleus leaves a nuclear recoil of low energy, which is difficult to observe in the detector. The decay leaves a single-photon signature. [Equation (3)]
- **Inside events, incoherent:** The incoherent scattering on nucleons leads to a signature similar to NC neutrino events, whereas the scattering on electrons results in a single electron. In addition, there is a coincidental displaced single-photon event from the heavy-neutrino decay. [Equation (3)]

Inside spectra with arbitrary normalisation

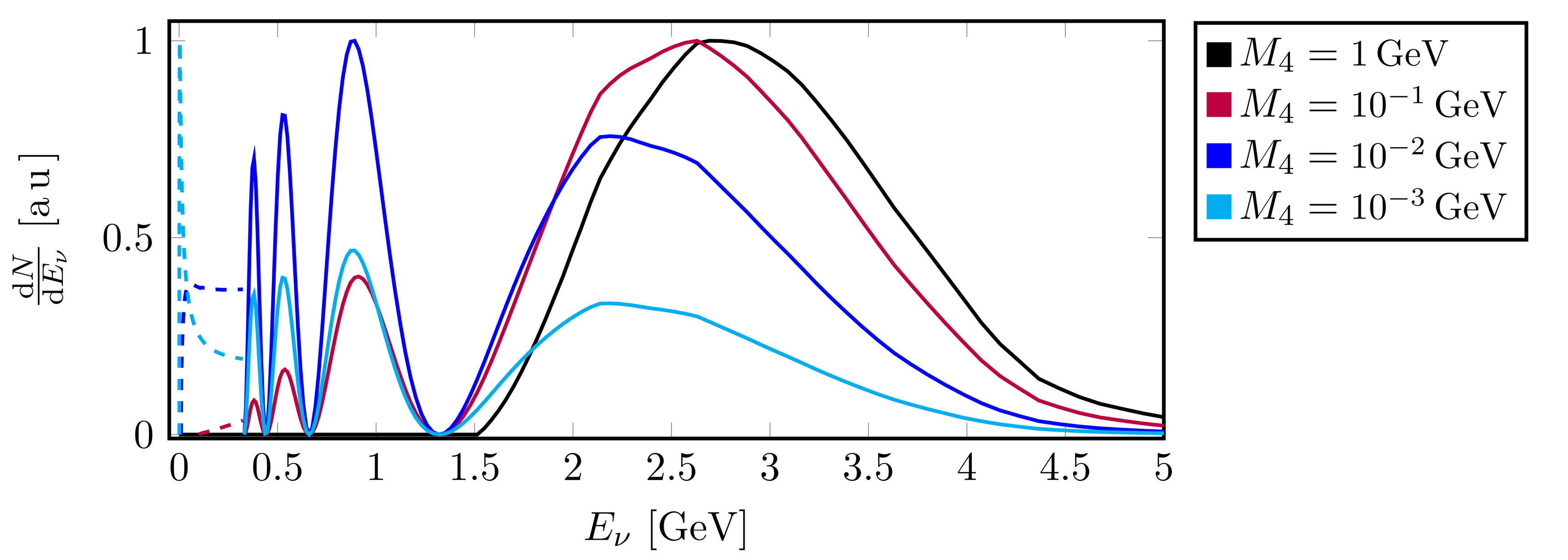

Figure 2: Spectra for inside events at various masses, normalised so that the peak is 1. At low energies (dashed), we replace the oscillation probability with $1/2$ to account for the averaging of fast oscillations. Outside event spectra are similar.

Inside (solid) and outside (dashed) 6 events/year at DUNE FD

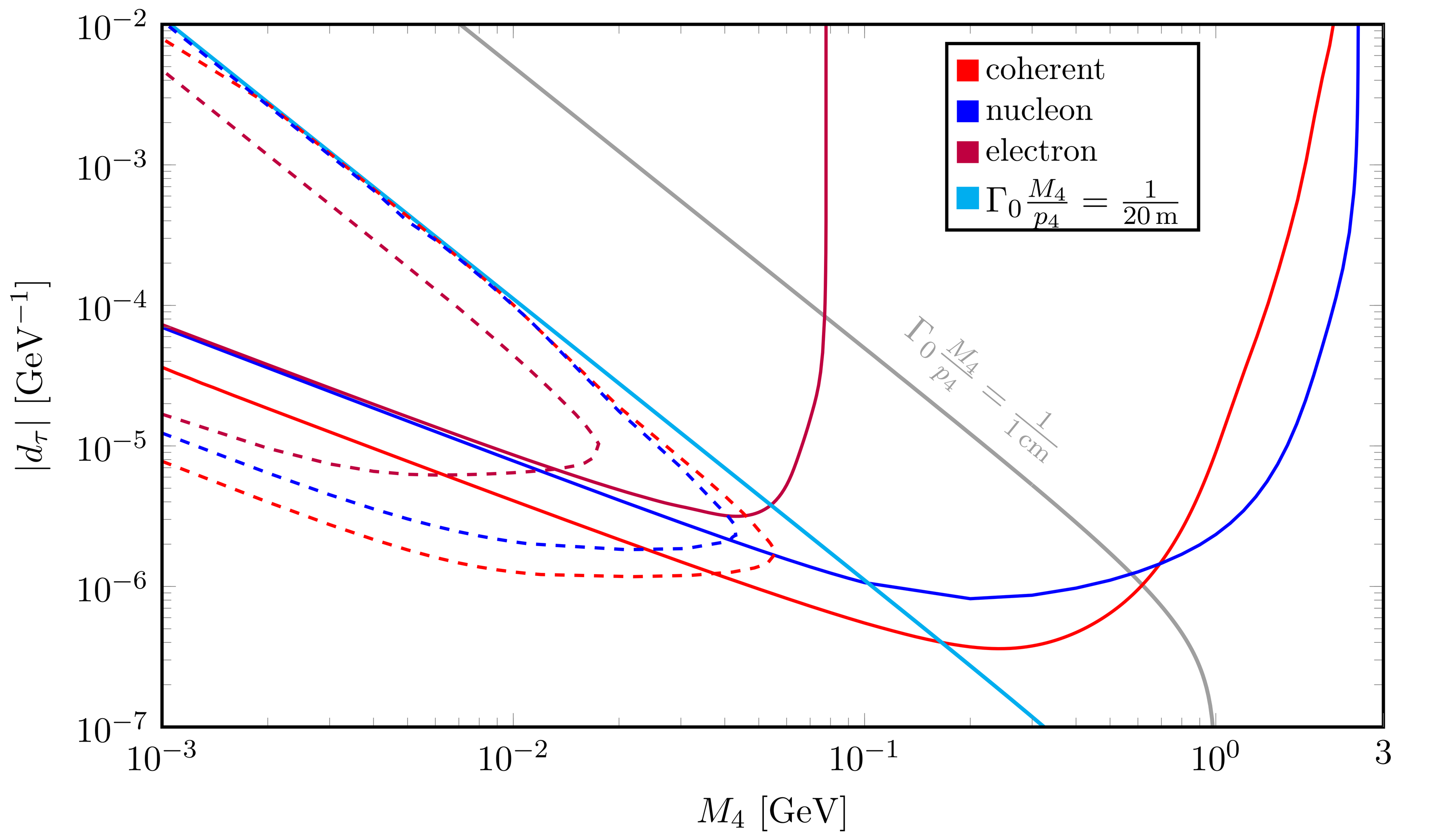

Figure 3: 6-events/year curves for inside (solid) and outside (dashed) events at the DUNE FD for coherent scattering on nuclei (red), incoherent scattering on nucleons (blue) as well as electrons (purple). Our approximations for outside events break down at the upper curve, as decays occur very close to the detector (cyan line). This effect is negligible as inside-events will dominate. In grey is indicated when the decay-length is of the order of DUNE's spatial resolution.

$$\frac{dN}{dE_4} = N_{\text{mod}}\frac{\rho_N}{2\pi}\int_0^{\theta_b^{\max}}\sin\theta_b\, d\theta_b \int_{r_{\min}}^{r_{\max}} L_{\text{ND}}^2\, dr_p \sum_{M_T}\left[\frac{d^2\Phi}{d\Omega_b\, dE_\nu}\frac{dE_\nu}{dE_4}P_{\text{osc}}\cdot\varepsilon_{\varphi_b}\cdot P_{\text{decay}}(\ell)\frac{d\sigma}{d\cos\theta_s}\Delta\Omega_s\cdot\varepsilon(p_4)\right]_T \qquad (2)$$

$$\frac{dN}{dE_\nu} = N_{\text{mod}}\frac{L_{\text{ND}}^2}{L_{\text{FD}}^2}\rho_N A_{\text{det}}\frac{d\Phi}{d\Omega\, dE_\nu}\bigg|_{\theta_b=0} P_{\text{osc}}\left(\frac{L_{\text{FD}}}{E_\nu}\right)\sum_{M_T}\int_0^{L_d} dz \int_{-1}^{1} d\cos\theta_s \frac{d\sigma_T}{d\cos\theta_s}\Pi\left(\ell_d^0\right)P_{\text{dec}}(\ell_d^0)\varepsilon(p_4). \qquad (3)$$

3. Results

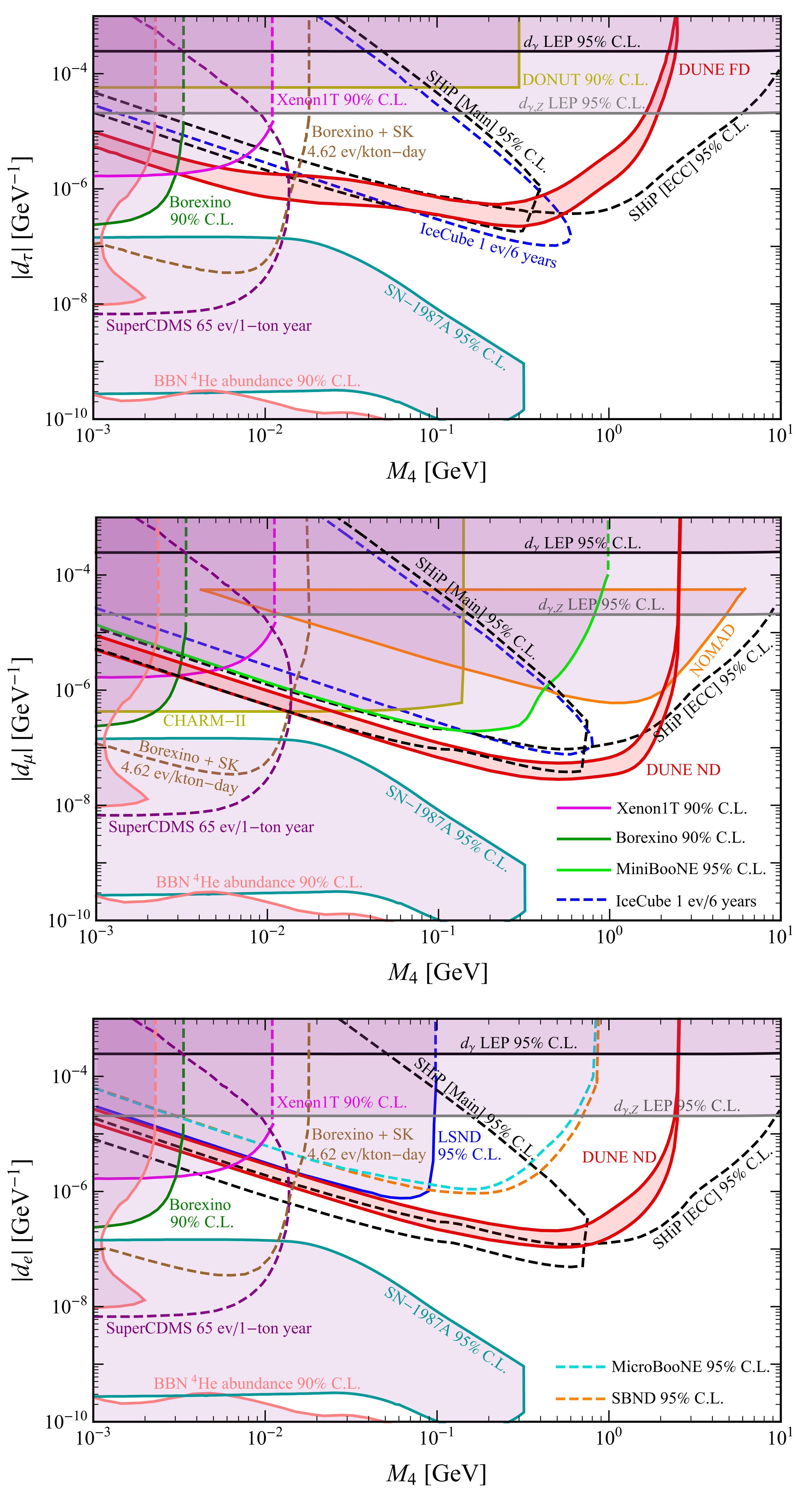

Figure 5: 2 − 20 events/year (red band), corresponding to 95% C.L. sensitivity over 5 years with 25 − 2500 background events (this work) for d_τ (above), d_μ (middle) and d_e (below) in addition to various existing constraints, estimated exclusions (both in dashed) and projected sensitivities (solid boundaries, shaded regions with extrapolations dashed). Most limits and sensitivities come from [1, 2] but for the full list see our paper (in abstract).

References

[1] G. Magill, R. Plestid, M. Pospelov and Y.-D. Tsai, Phys. Rev. D **98** (2018), 115015; [arXiv:1803.03262]
[2] V. Brdar, A. Greljo, J. Kopp and T. Opferkuch, JCAP **01** (2021), 039; [arXiv:2007.15563]