Looking for Beyond Standard Model short-lived particles with secondary production

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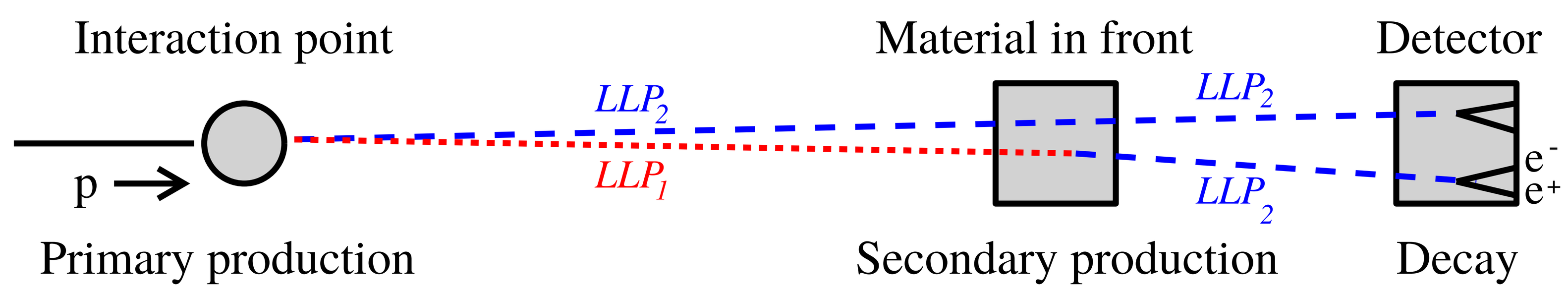
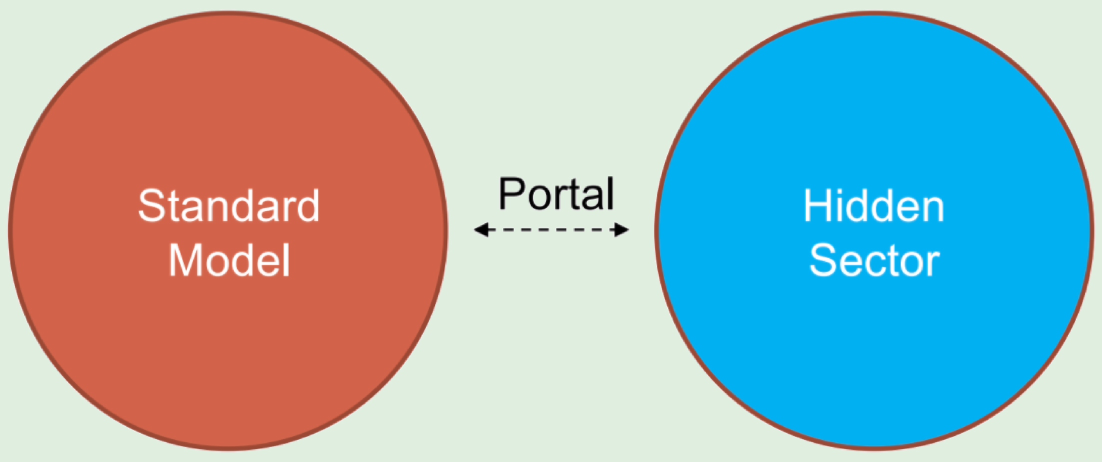
Many beyond the Standard Model (BSM) scenarios postulate the existence of new long-lived particles, leading to interesting experimental signatures such as, e.g., highly displaced decays. Examples of such portals appear both at the renormalizable and non-renormalizable levels and are often assumed, for simplicity, to have minimal content of new physics species required to study their phenomenology. Going beyond such most simplified models, however, is typically more theoretically appealing and can lead to other interesting effects. In particular, large couplings in the dark sector can induce efficient interactions, in which **new particles can scatter and change their identity in front of the detector. This leads to an interplay between short and long-lifetime regimes**. We illustrate the prospects of such searches in representative CERN-based experiments FASER, SHiP and MATHUSLA for *illustrative models with inelastic dark matter, neutrino dipole portal and dark neutrino portal, among others*.



Dark Sector connection to Standard Model

- We illustrate impact of secondary production in non-minimal BSM physics scenarios extending simplified models of interactions between SM and New Physics



– the models we consider extend the following renormalizable portals:

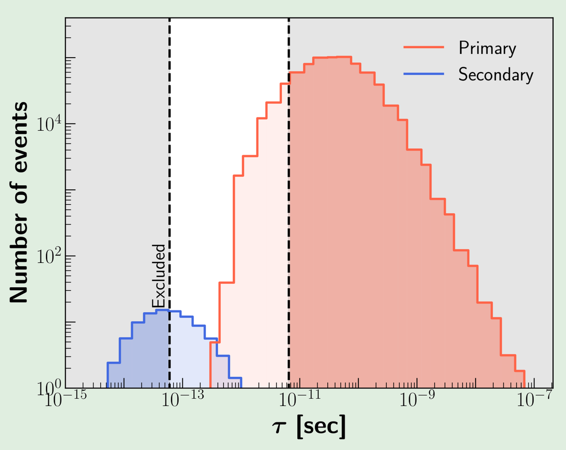
$$\mathscr{L}_{\text{vector portal}} = -\tfrac{\epsilon}{2}F'_{\mu\nu}F^{\mu\nu}$$
$$\mathscr{L}_{\text{scalar portal}} = \alpha_1 S H^\dagger H + \alpha S^2 H^\dagger H$$
$$\mathscr{L}_{\text{neutrino portal}} = F_\ell\left(\epsilon_{ab}\bar{L}_{\ell,a}H_b\right)N.$$

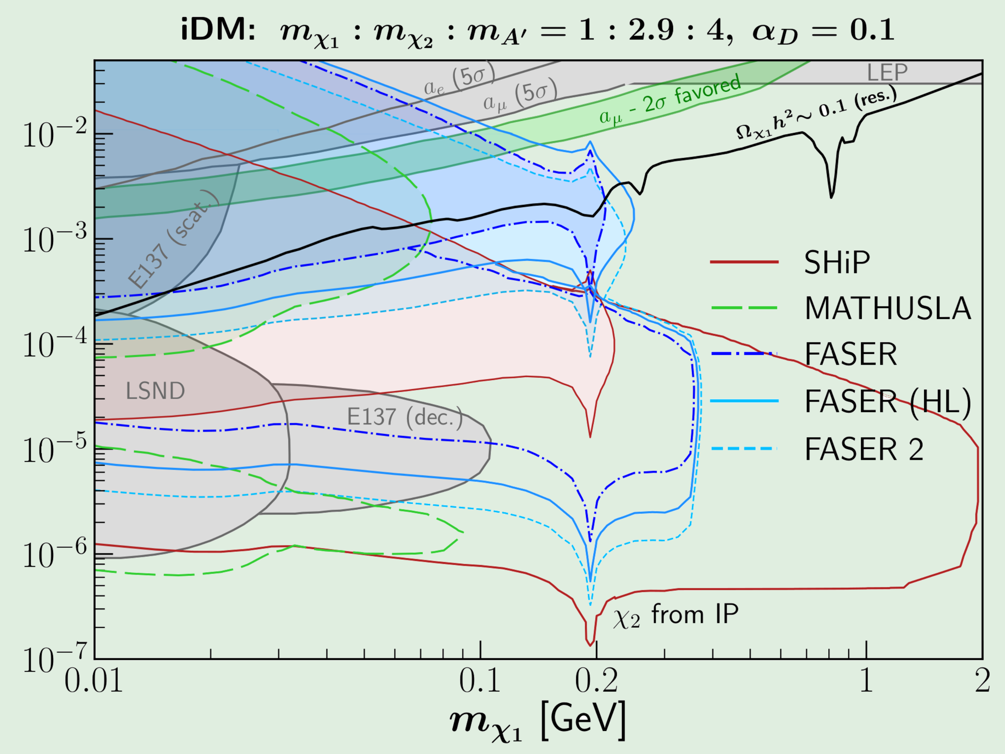
Inelastic Dark Matter

- Secondary production in iDM vector portal model containing two additional fermions with split masses

$$\mathscr{L}_{\text{int}} \supset g_{12}\bar{\chi}_2\gamma^\mu\chi_1 X_\mu + h.c$$

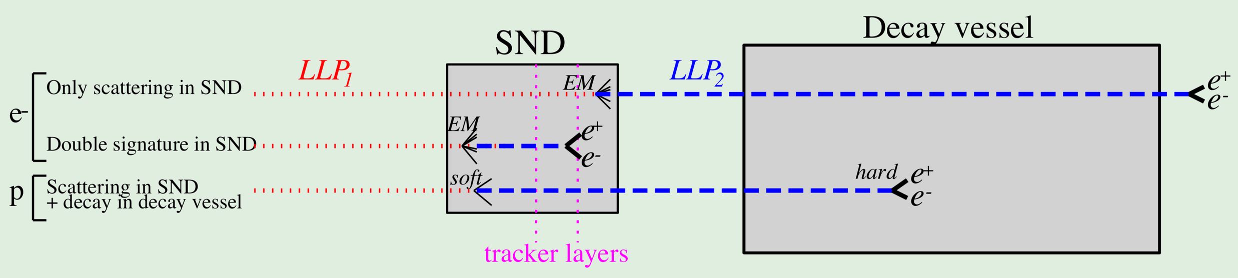
extends the sensitivity of FASER, SHiP and MATHUSLA towards $\Omega h^2 \sim 0.12$ and $(g-2)_\mu$ regions.



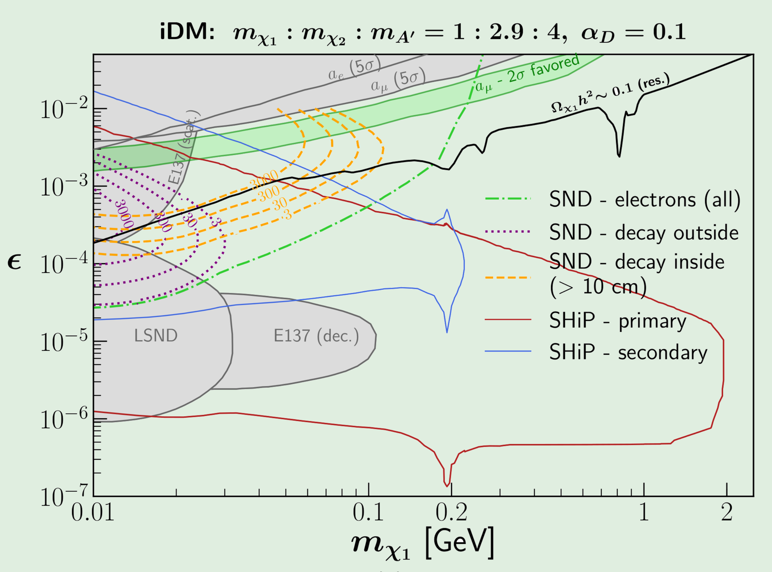


Signatures in emulsion detectors

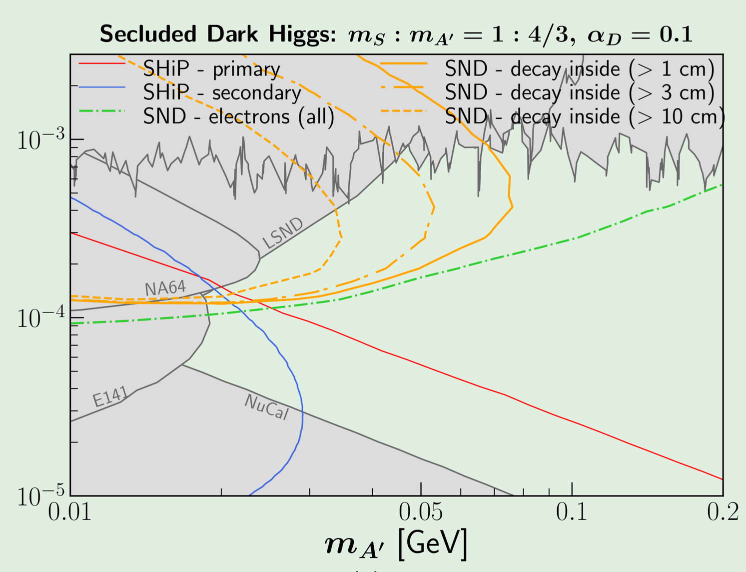
- Scatterings with electons in the emulsion detector (shown for SHiP experiment and its SND detector) greatly extends the covarage of parameter space towards smaller lifetimes of the LLP.



- On the left (a) we show the impact on the coverage of parameter space of inelastic DM model.
- On the right (b) we show the impact on the coverage of parameter space of Dark Higgs-Dark Photon model.



(a)



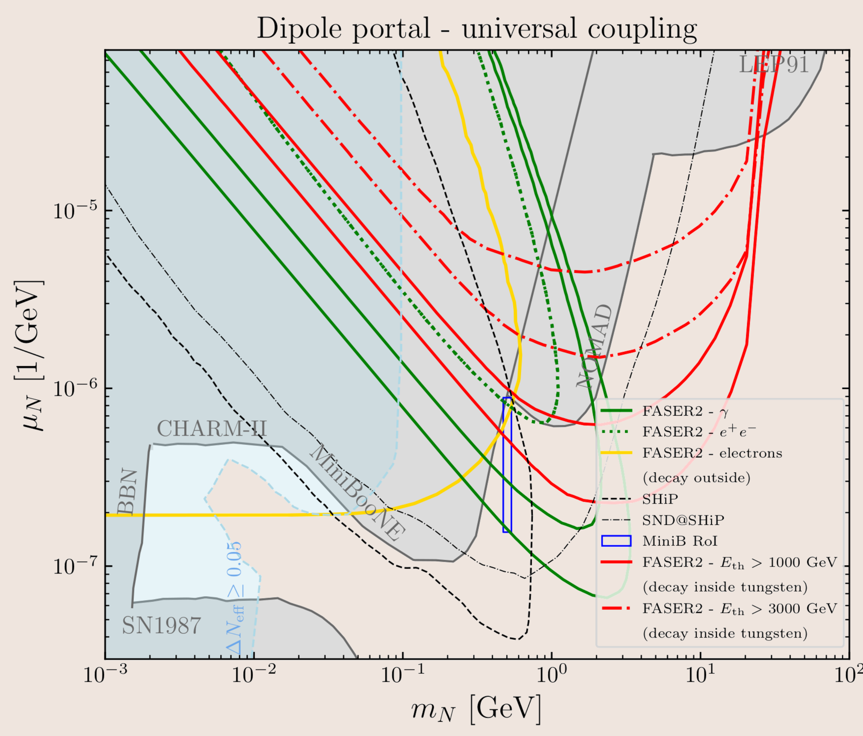
(b)

Neutrino magnetic dipole portal

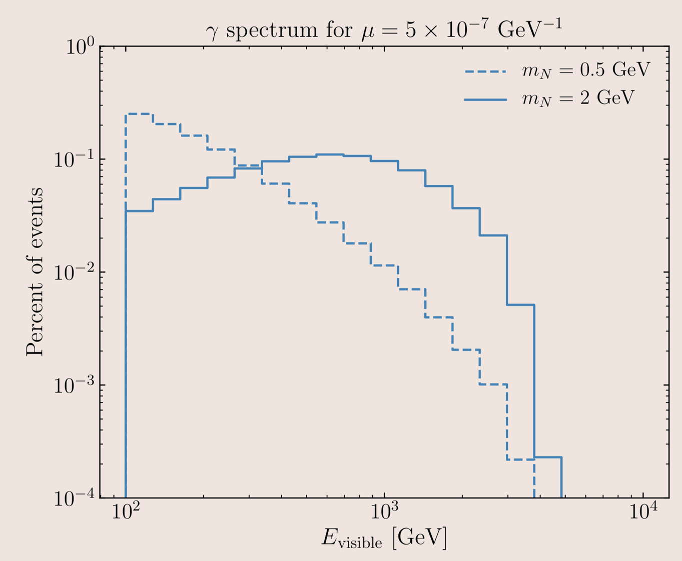
- Non-minimal models with sterile neutrinos generically generate sizable dimension-6 magnetic dipole operator:

$$\mathscr{L} \supset \mu_N \bar{\nu}_L \sigma_{\mu\nu} N_R F^{\mu\nu},$$

which allows for fast heavy neutrino decay $N \to \nu + \gamma$. Such scenario was invoked as possible explanation of, e.g., MiniBooNE or XENON1T anomalies.



(a)



(b)

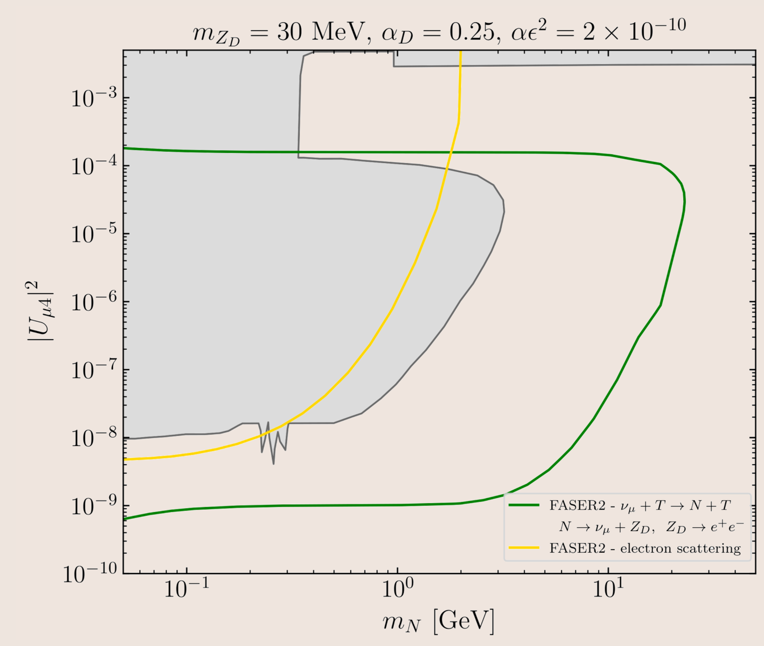
- We found that in the universal coupling scenario, FASER 2 will cover the region of interest related to MiniBooNE anomaly, as well as other physically important regions of parameter space.

Dark Neutrino Portal

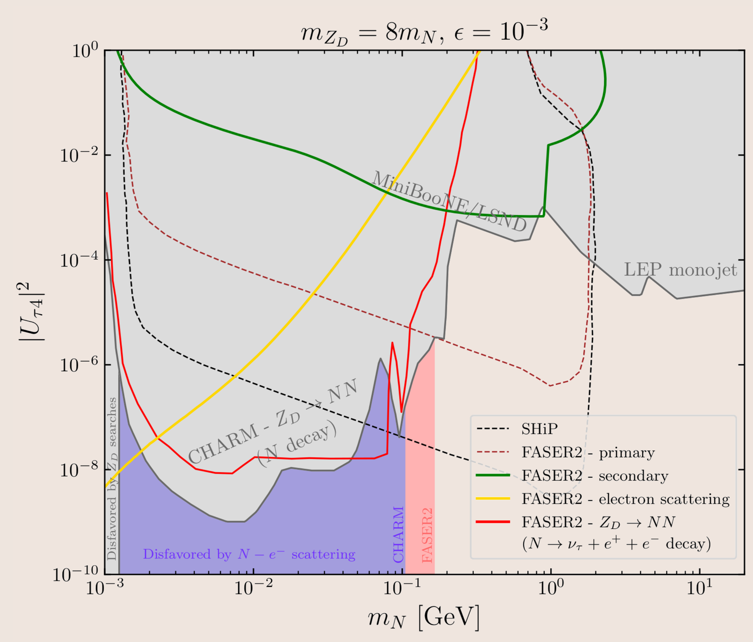
- Sterile neutrino model with dark photon which couples vectorially to neutrino sector

$$\mathcal{L}_{\mathcal{D}} \supset g_{\mathcal{D}} Z^\mu_{\mathcal{D}} \bar{\nu}_{\mathcal{D}}\gamma_\mu\nu_{\mathcal{D}}, \quad \nu_\alpha = \sum_{i=1}^{3} U_{\alpha i}\nu_i + U_{\alpha 4}N_{\mathcal{D}}, \quad \alpha = e, \mu, \tau, \mathcal{D}$$

is known to provide an elegant mechanism of mass generation of light neutrinos as well as yield interesting "double bang" signature that could be related to MiniBooNE anomaly.



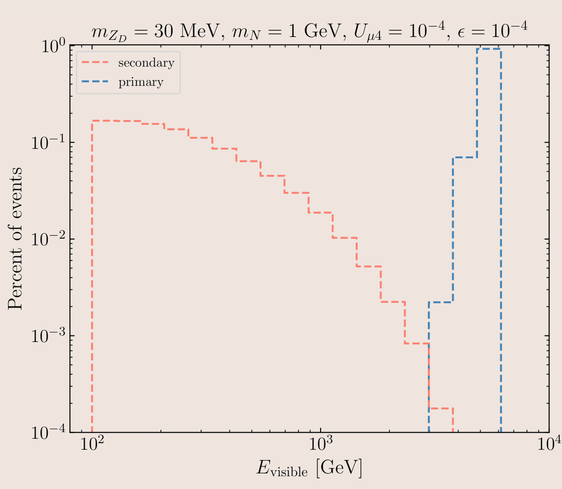
(a)



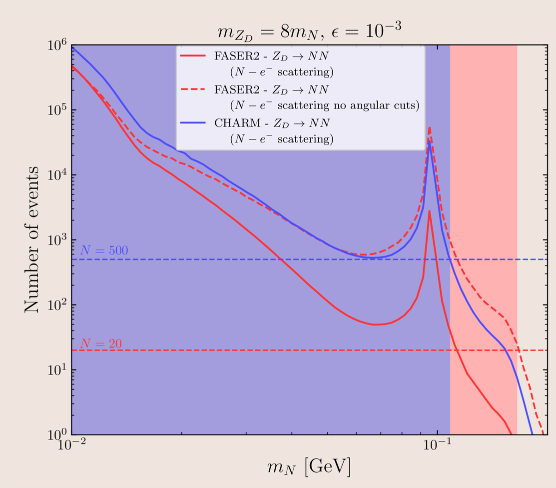
(b)

(a) $m_{Z_D} < m_N$
i) N is produced by upscattering
ii) we show FASER 2 sensitivity in the scenario of dominant mixing with ν_μ.

(b) $m_{Z_D} > m_N$
i) N is produced by Z_D and mesons decays ii) we show FASER 2 sensitivity in the scenario of dominant mixing with ν_τ and compare it to the existing CHARM bounds.



(a)



(b)

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Takeaway

- *Secondary production of LLPs can take place right in front of the detector which extends the sensitivity of intensity frontier experiments to shorter lifetimes.*
- It allows for good discovery prospects of BSM physics, employing distinct experimental signatures. We illustrate this for a) standard search for two high-energy oppositely- charged tracks b) the single-electron scattering signature c) the search for high-energy photons appearing in the detector.