Higgs phenomenology as a proble of sterile neutrinos

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based on Butterworth, **MC**, Englert, Spannowsky, Titov; *1909.04665*

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New physics needed for explaning neutrino masses: type I *see-saw*, add N

(i) At least one N can be as light as the electroweak scale

(ii) N is generally part of a bigger sector with heavier particles [e.g. Dev et al ‘10, ‘16]

If both (i) and (ii) hold simultaneously, one must use the NSMEFT:

dim-5

$$\mathcal{O}_{LH}^{ij} = \overline{L_i^c}\tilde{H}^*\tilde{H}^\dagger L_j\,,$$

$$\mathcal{O}_{NNH} = \overline{N^c}NH^\dagger H\,.$$

dim-6

$$\mathcal{O}_{HN} = \overline{N}\gamma^\mu N H^\dagger i\overleftrightarrow{D}_\mu H\,,$$

$$\mathcal{O}_{LNH}^{i} = \overline{L_i}N\tilde{H}H^\dagger H\,,$$

$$\mathcal{O}_{HNe}^{i} = \overline{N}\gamma^\mu e_{iR}\tilde{H}^\dagger iD_\mu H\,,$$

$$\mathcal{O}_{NB}^{i} = \overline{L_i}\sigma^{\mu\nu}N\tilde{H}B_{\mu\nu}\,,$$

$$\mathcal{O}_{NW}^{i} = \overline{L_i}\sigma^{\mu\nu}N\sigma_I\tilde{H}W_{\mu\nu}^I\,,$$

$+$ four-fermions

The NSMEFT was built in a series of works:

Aguila et al ‘08, Aparici et al ‘09, Bhattacharya and Wudka ‘15, Liao an Ma ‘16

It has been fully renormalised in a series of recent papers:

MC and Titov ‘20, Datta et al ‘20, Datta et al ‘21

I want to focus on the following regime:

$$\mathcal{O}_{LH}^{ij} = \overline{L_i^c}\tilde{H}^*\tilde{H}^\dagger L_j\,,$$

$$\mathcal{O}_{NNH} = \overline{N^c}NH^\dagger H\,.$$

LNV only in N interactions

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$$\mathcal{O}_{NW}^{i} = \overline{L_i}\sigma^{\mu\nu}N\sigma_I\tilde{H}W_{\mu\nu}^I\,,$$

Avoid Z > γγνν

Avoid bound from W width

easily realised in theUV;

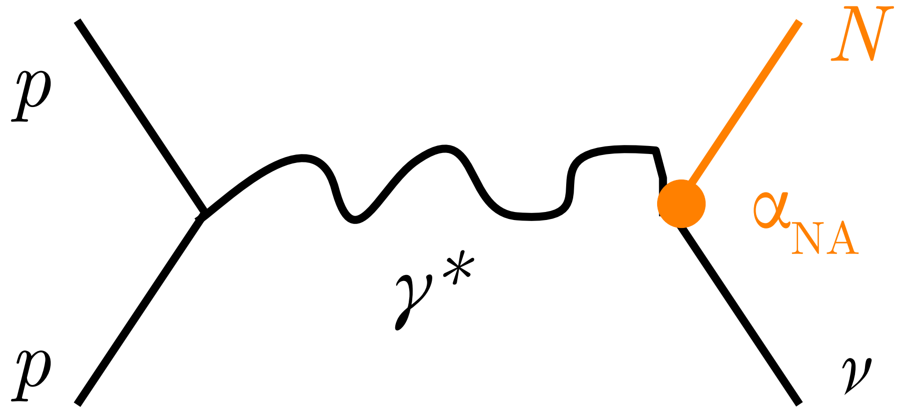
MC and Titov '20

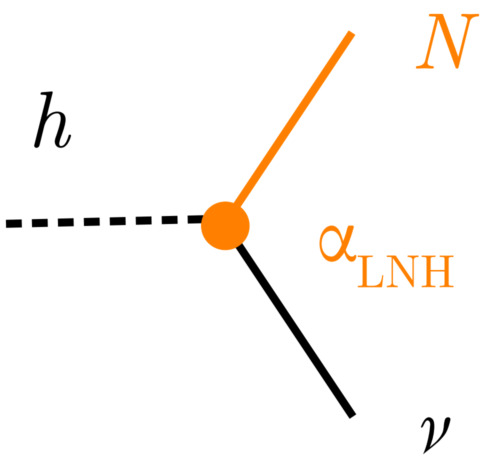
solely ONA

$\mathbf{N}\rightarrow\nu\gamma$ dominates for $m_N < 10$ GeV [Biekotter, **MC**, Spannowsky '20]

Differential cross section measurements [CONTUR, 1606.05296] constrain this NSMEFT, but not much

Big room for new physics signals:


p
p
N
α_{NA}
γ^*
ν


h
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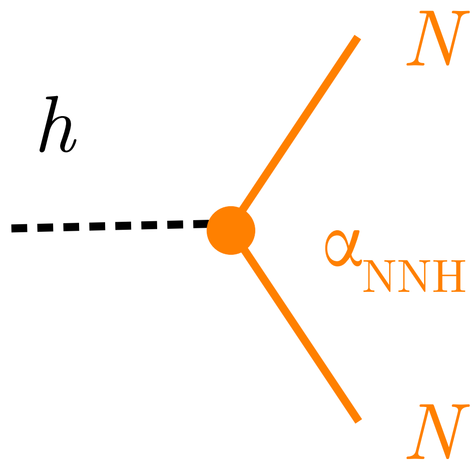
α_{LNH}
ν


h
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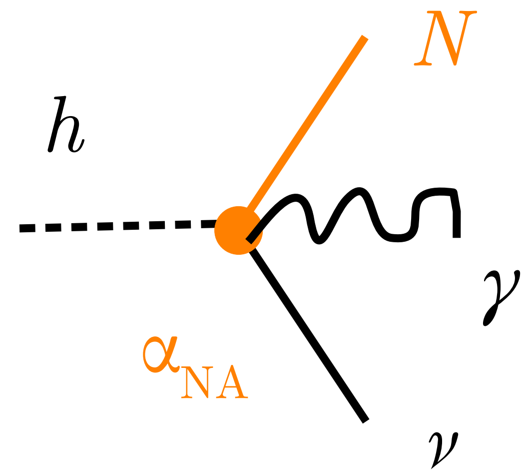
N


h
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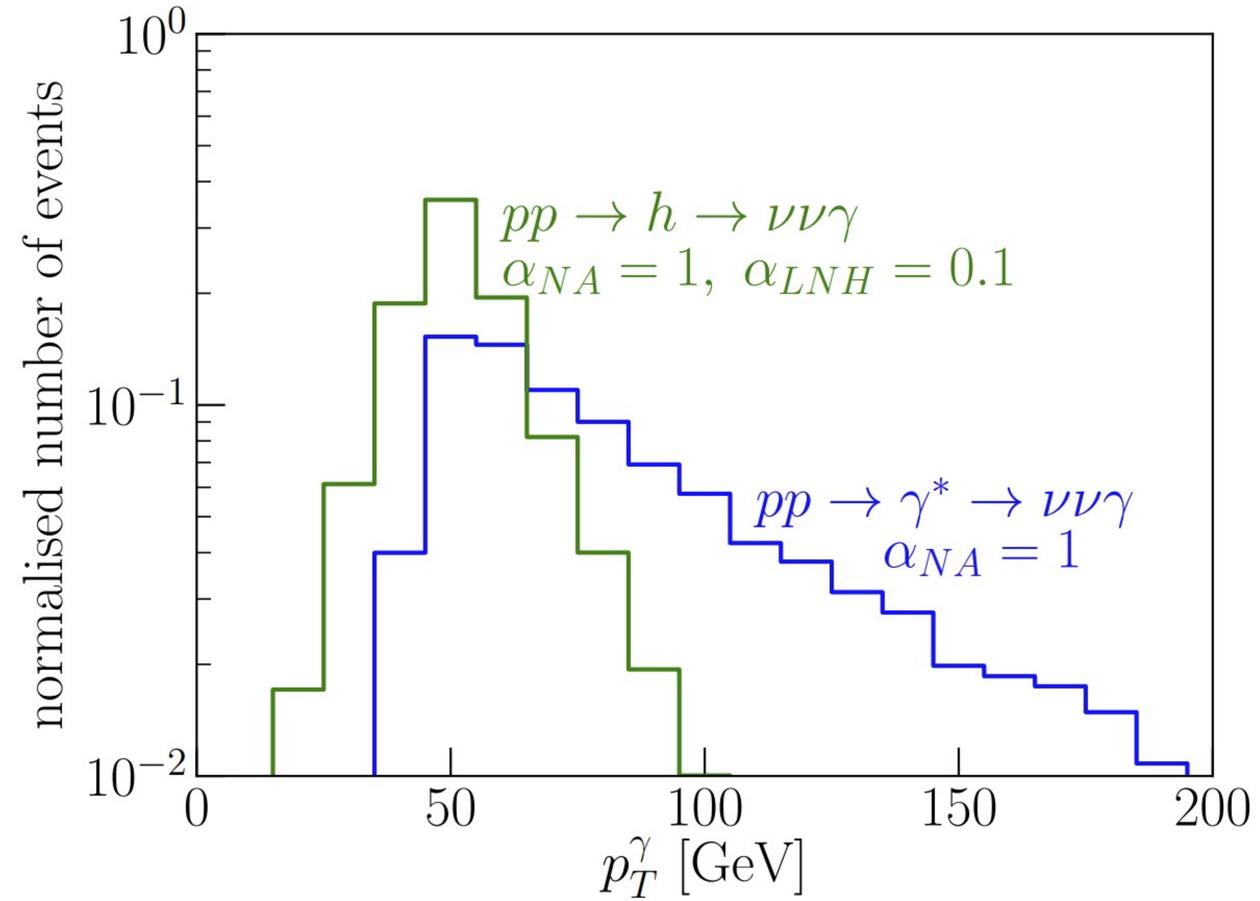
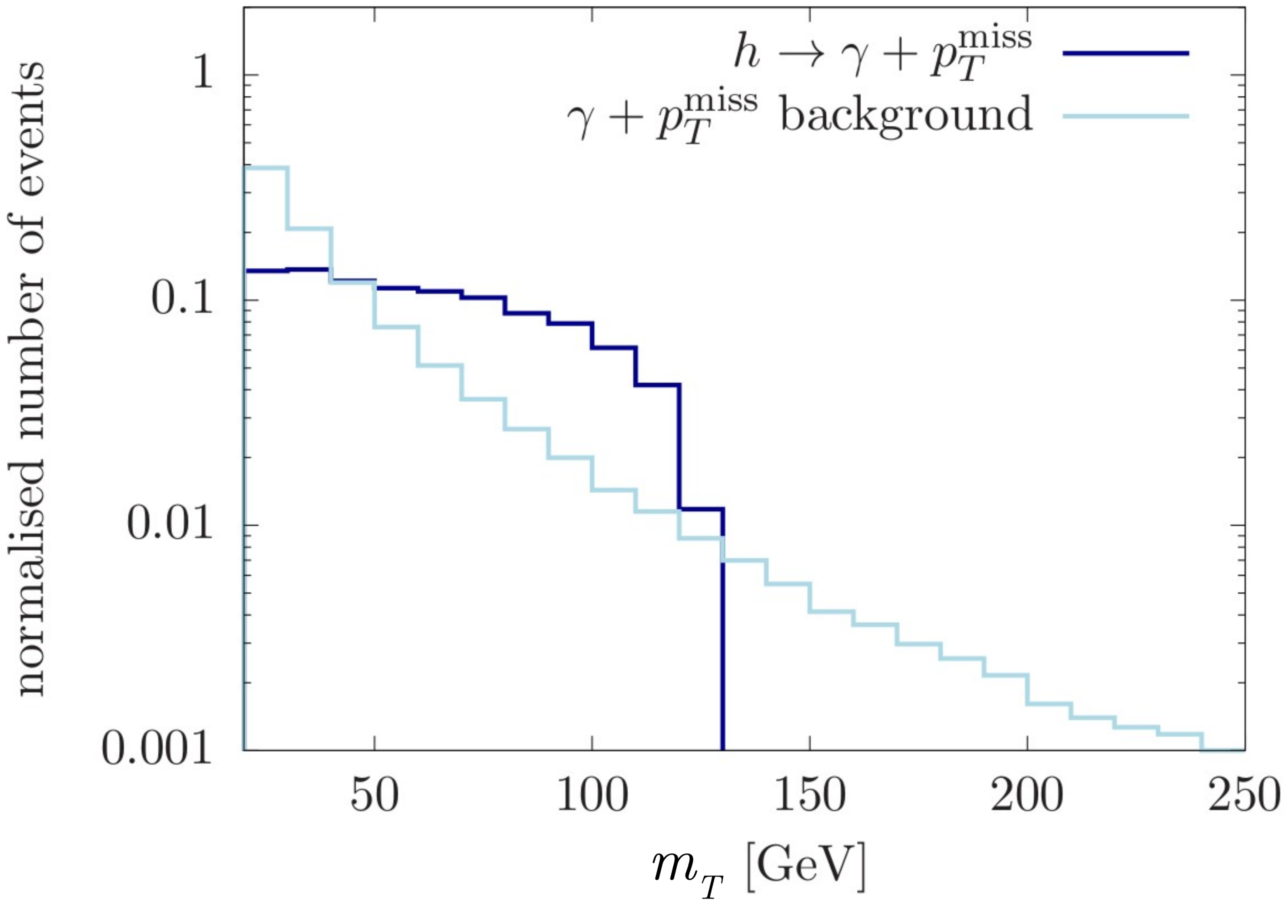
Cut-and-count search for monophoton plus missing energy [CMS, 1810.00196]:

PT(photon) > 175 GeV, ETMISS > 170 GeV, ...



Shape analysis for Higgs decays:

sideband substraction method for background
sensitivity to Higgs in diphotons despite low S/B



Expected results at the LHC at high luminosity (3/ab):

Note that the Higgs width is very small, so these bounds translate into strong potential constraints on Wilson coefficients

$$\mathcal{B}(h \to \gamma + p_T^{\rm miss}) = 1.2 \times 10^{-4}\,,$$
$$\mathcal{B}(h \to \gamma\gamma + p_T^{\rm miss}) = 4.2 \times 10^{-5}\,,$$

Expected results at the LHC at high luminosity (3/ab):

Operator	$\alpha_{\rm max}$ for $\Lambda = 1$ TeV	$\Lambda_{\rm min}$ [TeV] for $\alpha = 1$	Channel
$\mathcal{O}_{LNH}$	4.2×10^{-3}	15	$h \to \gamma + p_T^{\rm miss}$
$\mathcal{O}_{NNH}$	5.3×10^{-4}	1900	$h \to \gamma\gamma + p_T^{\rm miss}$
$\mathcal{O}_{NA}$	0.21	2.2	$h \to \gamma\gamma + p_T^{\rm miss}$

TABLE I: *Maximum (minimum) value of α (Λ) for $\Lambda = 1$ TeV ($\alpha = 1$) allowed by the proposed searches quoted in the last column. We have assumed lepton flavour universality in couplings to N.*

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Conclusions

The NSMEFT captures a broad range of new physics models that explain neutrino masses

Some directions of the EFT predict rare Higgs decays not yet explored

Dedicated searches could be sensitive to new physics in the range $[2.2 - 1500]$ TeV!

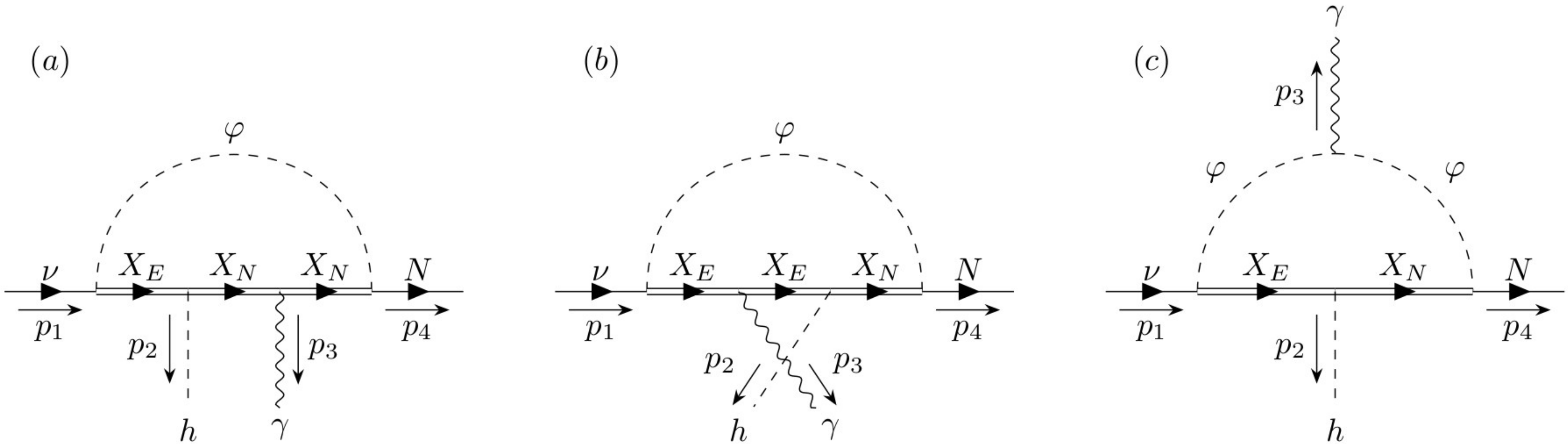
Thank you!

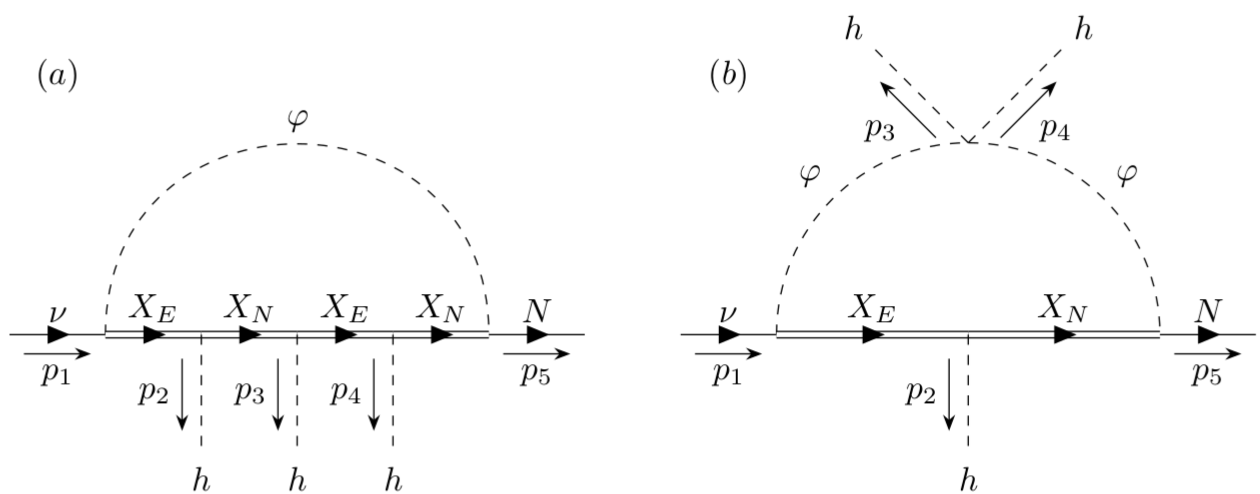
Backup

An explicit UV model:

$$
\begin{aligned}
L = {} & \overline{X_E}(i\not{D} - M_{X_E})X_E + \overline{X_N}(i\not{D} - M_{X_N})X_N \\
& + (D_\mu\varphi)^*(D^\mu\varphi) - M_\varphi^2\varphi^*\varphi - \lambda_{\varphi H}(\varphi^*\varphi)(H^\dagger H) \\
& + \left[g_X \overline{X_E}\tilde{H}X_N + g_L \overline{X_E}\varphi L + g_N \overline{X_N}\varphi N + \text{h.c.} \right]
\end{aligned}
$$

An explicit UV model:





Constraints from differential cross section measurements:

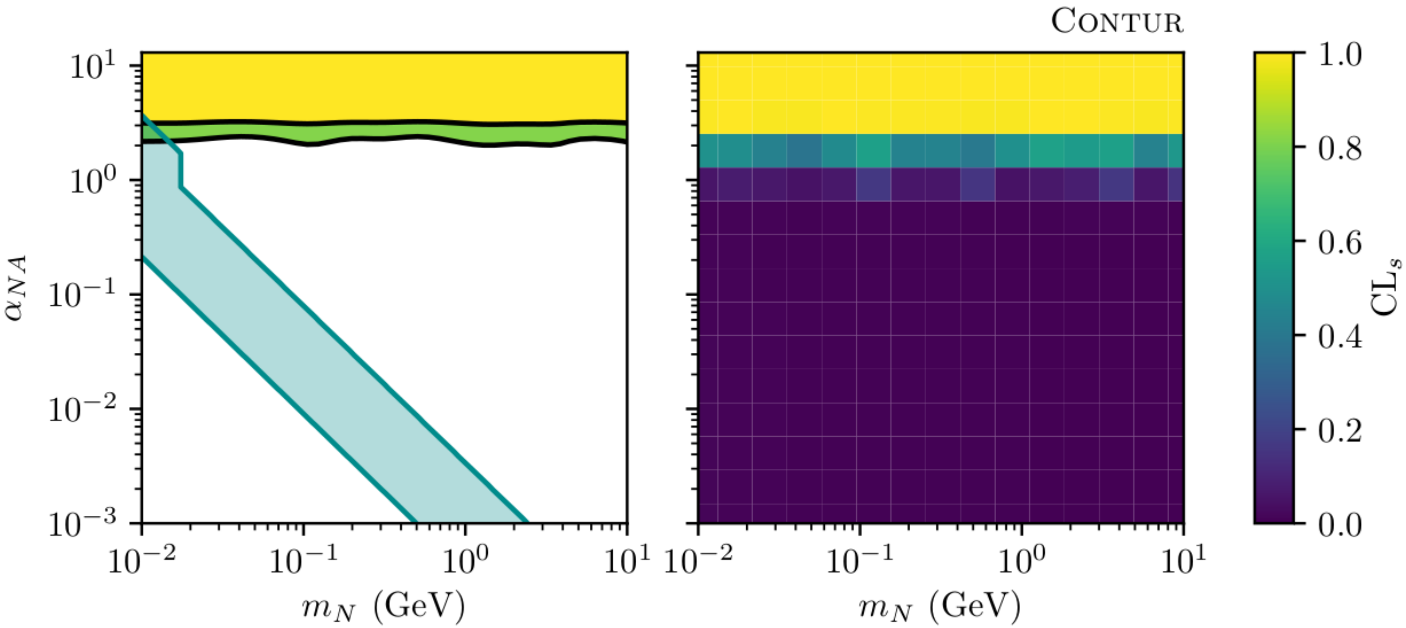


FIG. 2: CONTUR *exclusion in the* α_{NA}, m_N *plane, for* $\Lambda = 1$ *TeV. The left-hand inset shows the 2- and 1-*σ *exclusion contours based on the heatmap on the right. Within the diagonal cyan region the heavy neutrino would decay within the detector volume; above, it is effectively prompt and below, it is effectively stable.*