Joint Workshop of
the CEPC Physics, Software and New Detector Concept

Low scale partial composite Neutrinos and CEPC tests

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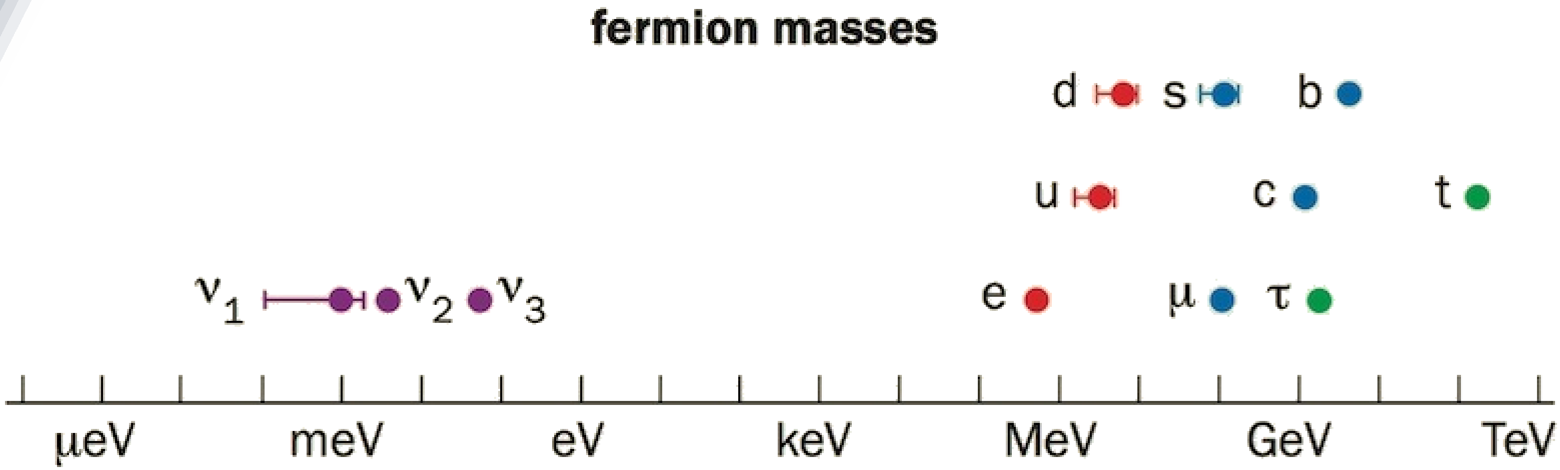
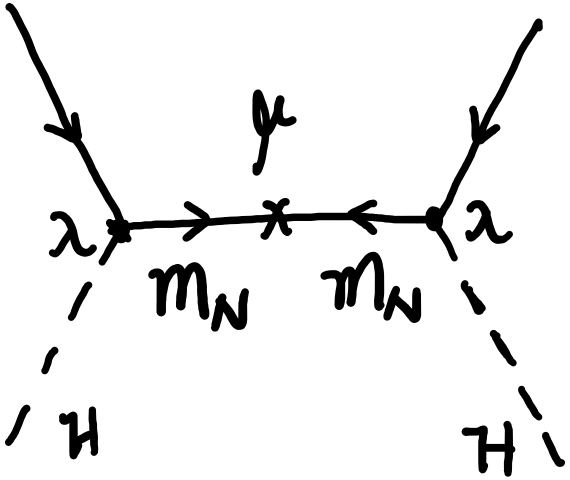
Apr.16th, 2021

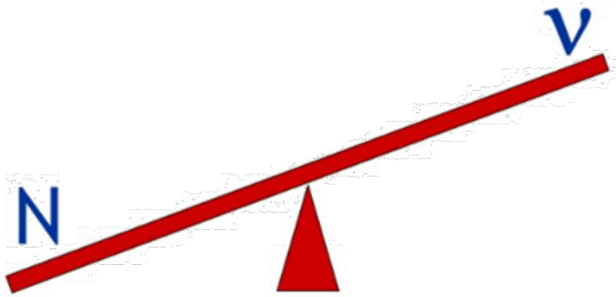
Chacko, Harnik, Fox, Liu, 2012.01443

Neutrino Mass Puzzle





$$L_{IR} \ni -m_N \bar{N} N - (\lambda \bar{L} \tilde{H} N_R + \mu N_L^2 + h.c.)$$



$$M = \begin{pmatrix} 0 & \lambda v_{EW} & 0 \\ \lambda v_{EW} & 0 & m_N \\ 0 & m_N & \mu \end{pmatrix}$$

In the $\mu \to 0$ limit, one Dirac Neutrino and one massless Wyle Fermion

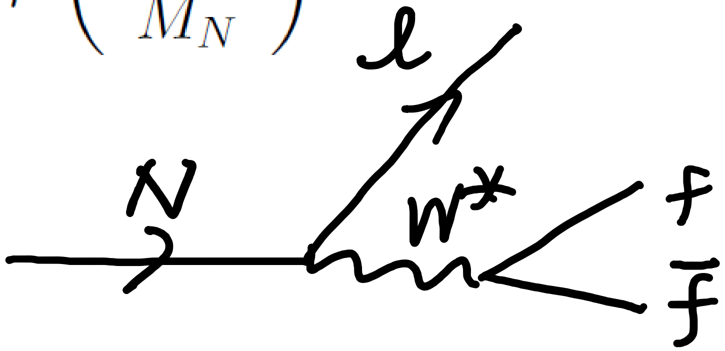
➔ $\mu \neq 0$, lightest eigenstate

$$m_\nu \approx \mu \left(\frac{\lambda v_{\rm EW}}{M_N} \right)^2$$

Inverse Seesaw , Mohapatra, Valle, 86’

Neutrino Mass Puzzle also leads to LLPs

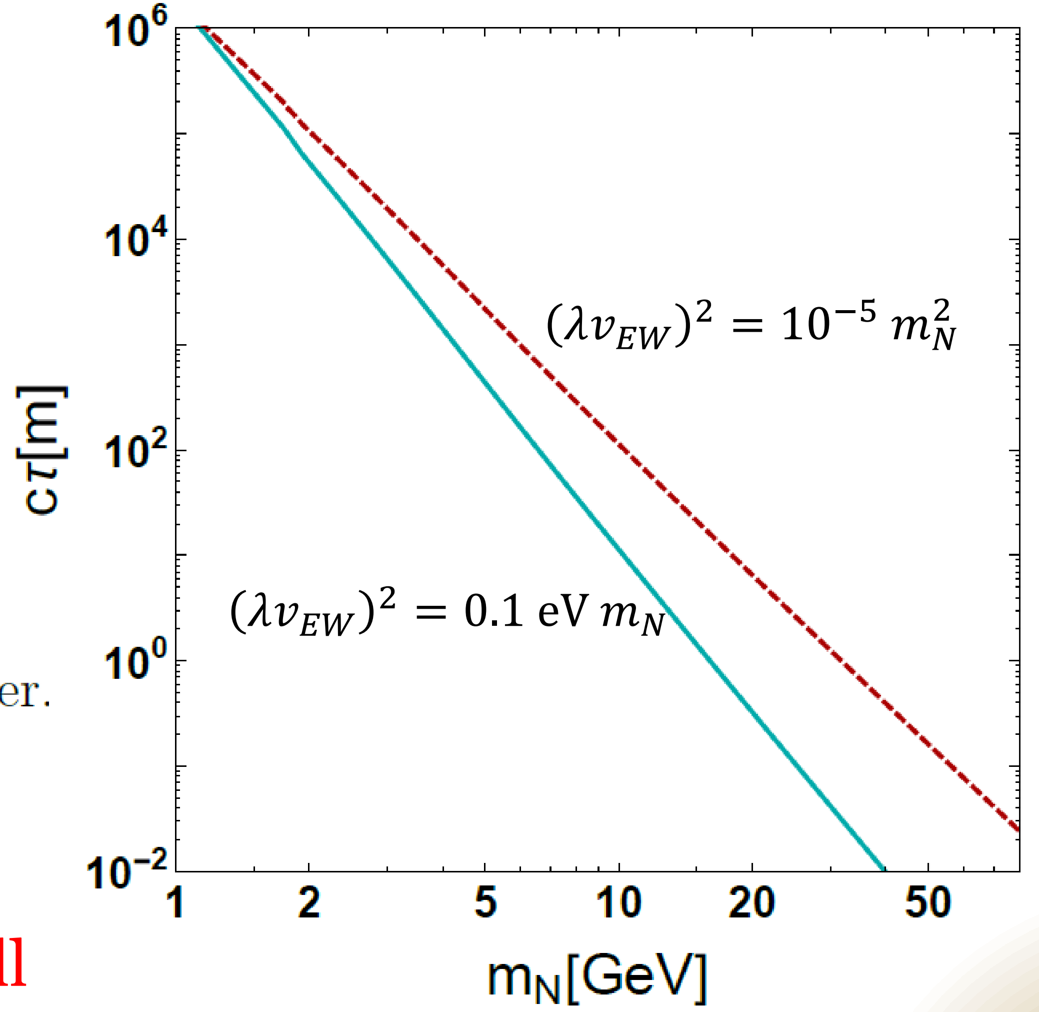
$$m_\nu \approx \mu \left(\frac{\lambda v_{\mathrm{EW}}}{M_N} \right)^2$$



Right-handed neutrino N is long-lived:

$$c\tau \simeq 7 \times 10^3 \times \left(\frac{\mathrm{GeV}}{m_N} \right)^5 \left(\frac{0.01\mathrm{eV}}{m_\nu} \right) \left(\frac{\mu}{\mathrm{MeV}} \right) \text{meter.}$$

But where do these small parameters come from?



Liu, Liu, Wang, Wang, 1904.01020

Chacko, Harnik, Fox, Liu, 2012.01443

As simple as QCD:
Dimensional transmutation generates small scales

A low scale partial composite model

Toy example:

$$L_{UV} \supset L_{QCD'} + \frac{LHu'd'd'}{M^3} + \frac{(u'_c d'_c d'_c)^2}{M^5}$$

$(u'd'd')$ confines to Neutron′= N

$$L_{IR} \ni -m_N \bar{N} N - (\lambda \bar{L} \widetilde{H} N_R + \mu N_L^2 + h.c.)$$

$$\Lambda_{QCD'} \qquad \left(\frac{\Lambda_{QCD'}}{M}\right)^3 \qquad \Lambda_{QCD'} \left(\frac{\Lambda_{QCD'}}{M}\right)^5$$

Consider the compositeness in general CFT

General CFT:

$$L_{UV} \supset L_{CFT} + \frac{\hat{\lambda}}{M^{\Delta-3/2}} \bar{L} \widetilde{H} O_N + \frac{\hat{\mu}}{M^{\Delta_{2N}-4}} O_{2N}$$

CFT generates

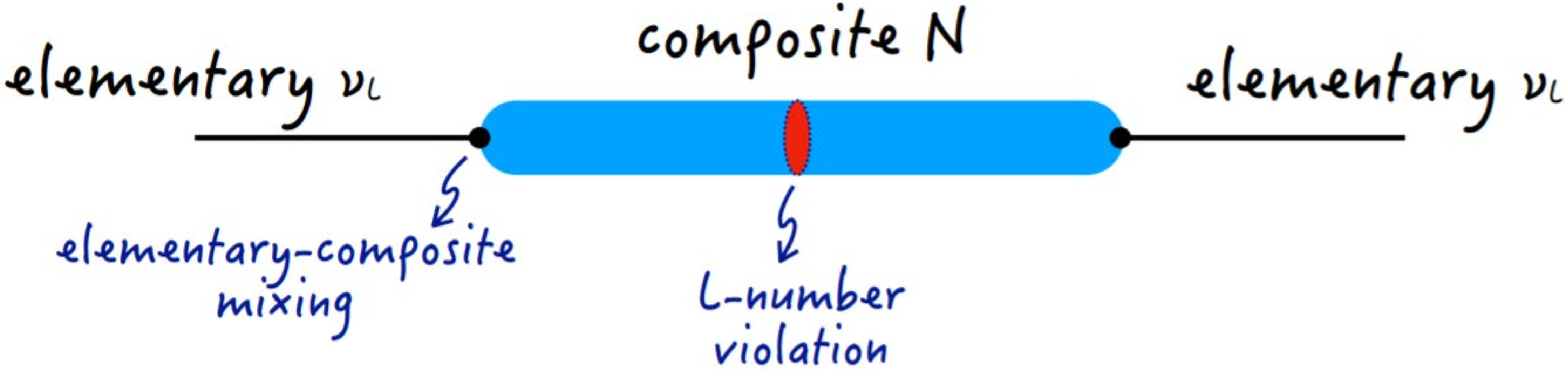
CFT deformation generates

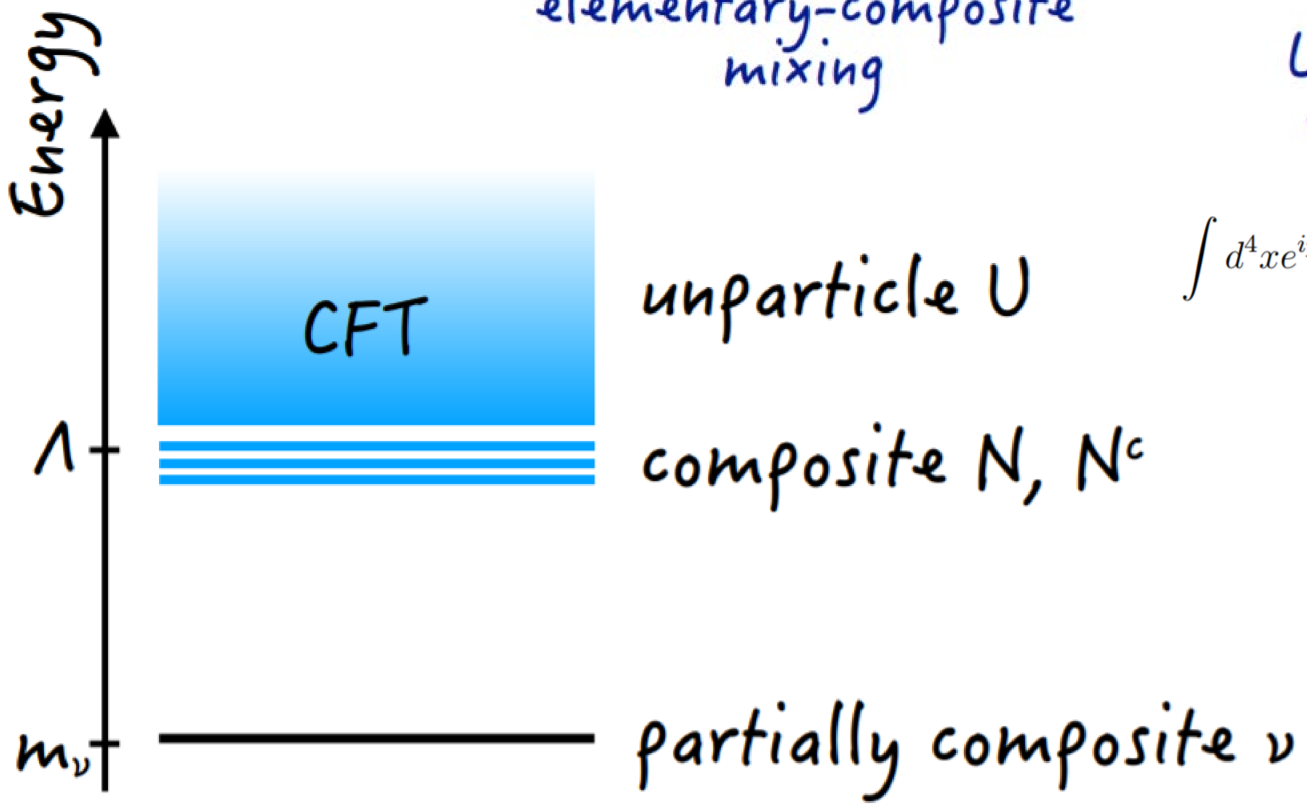
$$L_{IR} \ni -m_N \bar{N} N - (\lambda \bar{L} \widetilde{H} N_R + \mu N_L^2 + h.c.)$$

$$\Lambda \qquad C_\lambda \hat{\lambda} \left(\frac{\Lambda}{M}\right)^{\Delta-\frac{3}{2}} \qquad C_\mu \hat{\mu} \left(\frac{\Lambda}{M}\right)^{\Delta_{2N}-4}$$

Chacko, Harnik, Fox, Liu, 2012.01443

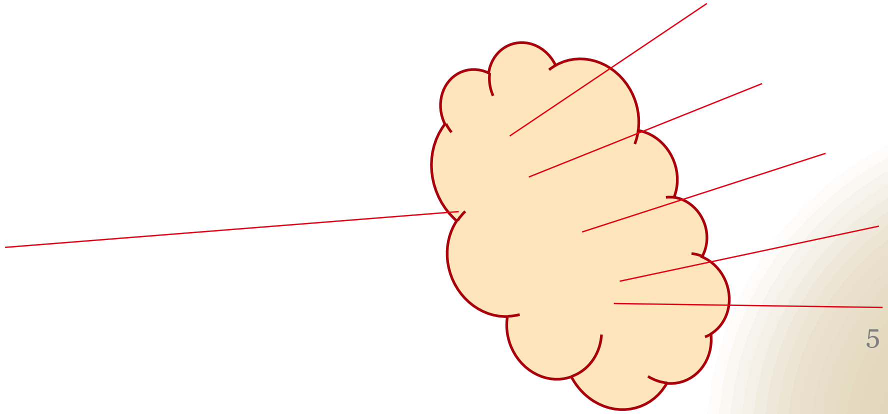
Our model: schematically





$$\int d^4x e^{ipx} \langle 0|T\left[\mathcal{O}_\mathrm{N}(x)\mathcal{O}^\dagger_\mathrm{N}(0)\right]|0\rangle = \frac{A_{\Delta_\mathrm{N}-1/2}}{2i\cos\left(\Delta_\mathrm{N}\pi\right)}\frac{\sigma^\mu p_\mu}{\left(-p^2-i\epsilon\right)^{5/2-\Delta_\mathrm{N}}}$$

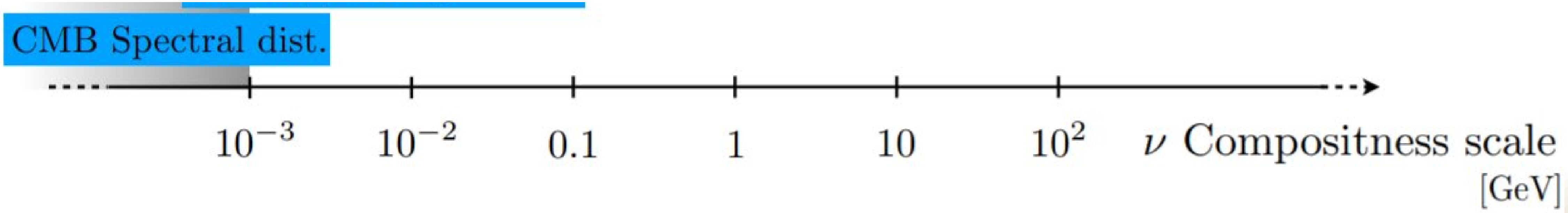
$$A_{\Delta_\mathrm{N}-1/2} = \frac{16\pi^{5/2}}{(2\pi)^{2\Delta_\mathrm{N}-1}}\frac{\Gamma\left(\Delta_\mathrm{N}\right)}{\Gamma\left(\Delta_\mathrm{N}-3/2\right)\Gamma\left(2\Delta_\mathrm{N}-1\right)}.$$



Rich Phenomenology and Comprehensive Considerations

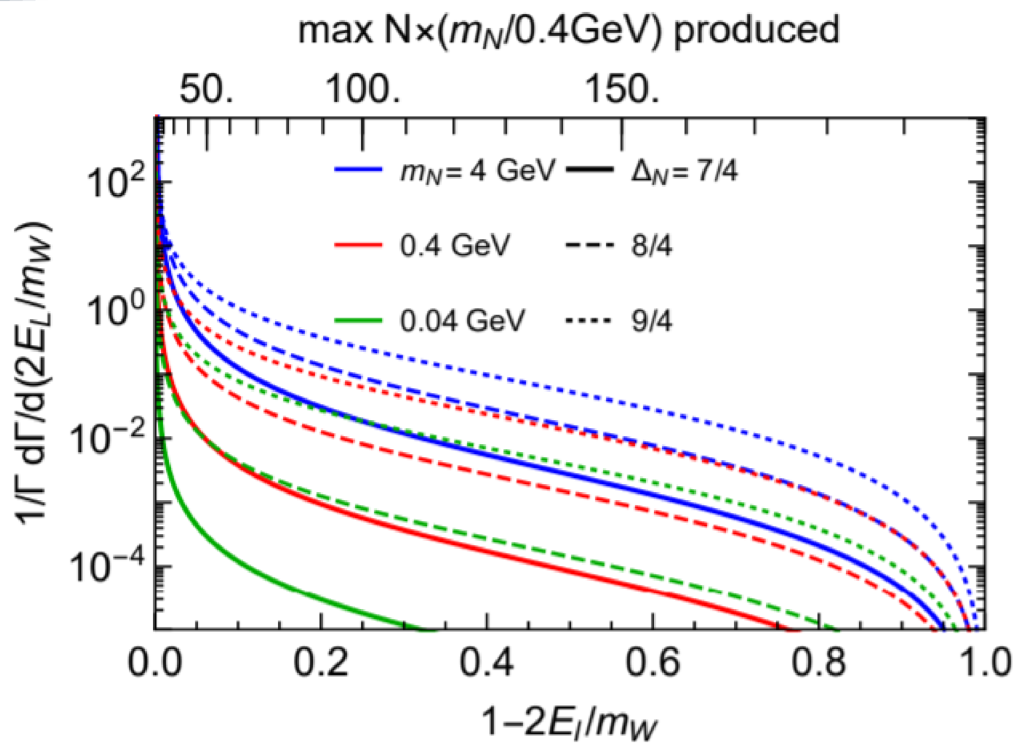
Cosmology
($\Delta N_{\rm eff}$)

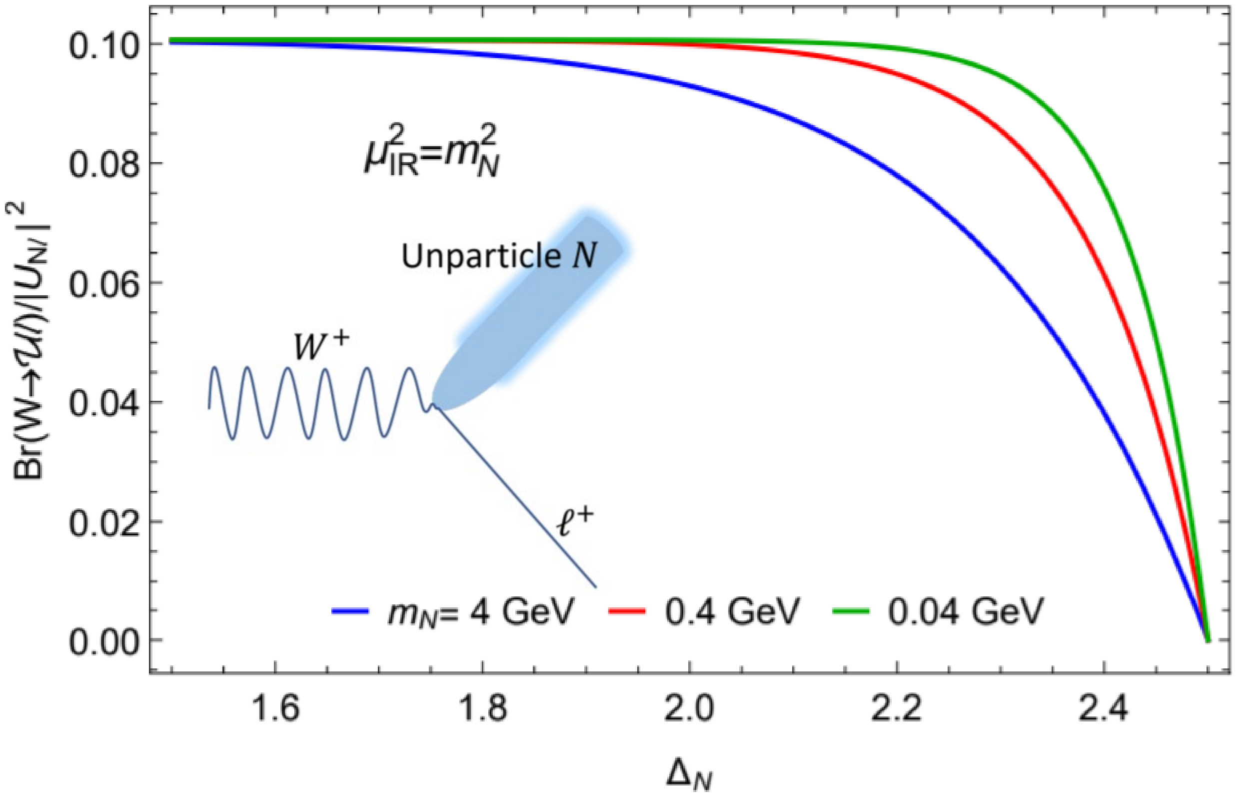
	$\hat{\lambda}$	$\hat{\mu}^c$	$\Delta_{\rm N}$	$\Delta_{\rm 2N^c}$	$\Lambda\,[\rm MeV]$	$M_{\rm UV}\,[\rm TeV]$	λ	$\mu^c\,[\rm MeV]$	$m_\nu\,[\rm eV]$
I	1	1	1.85	3.9	400	$M_{\rm Pl}$	8×10^{-8}	80	0.1
II	1	2	1.8	4.05	40	$M_{\rm Pl}$	4×10^{-7}	10^{-2}	0.045
III	5×10^{-5}	1	1.9	3.8	40	2×10^{3}	2×10^{-8}	7	0.05
IV	1	4×10^{-14}	2.4	2.25	400	2×10^{3}	3×10^{-7}	5	0.08
V	10^{-2}	5×10^{-3}	2.25	3.4	400	2×10^{3}	3×10^{-8}	300	0.05



$$m_\nu\,|_{\rm inv.seesaw} = \mu^c\left(\frac{\lambda v_{\rm EW}}{M_N}\right)^2 \qquad U_{N_\alpha \ell_i} = \frac{\lambda_{i\alpha}\, v_{\rm EW}}{M_{N_\alpha}}$$

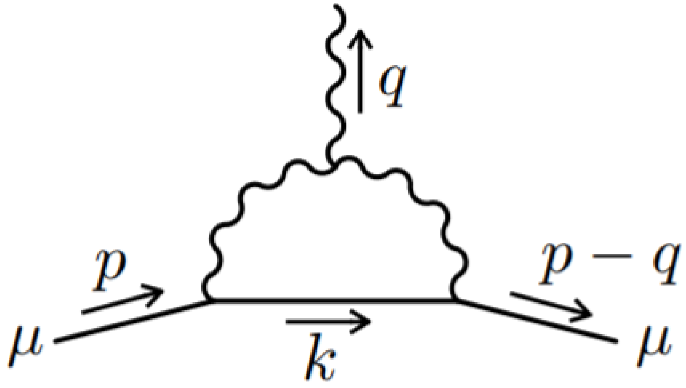
W, Z, H, meson decays into unNeutrinos

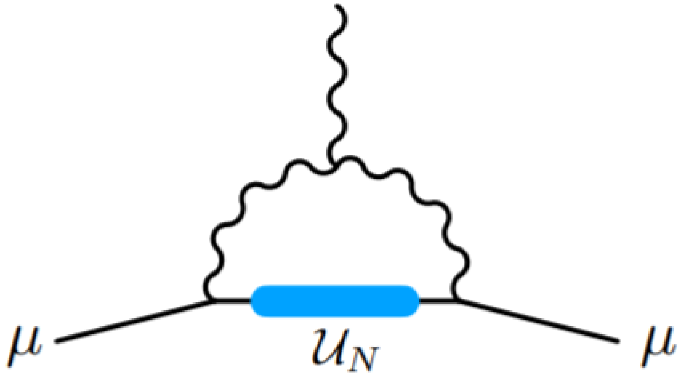




$$\Gamma(W \to \ell\mathcal{U}) = \sum_{\alpha=1}^{\mathcal{N}_N} m_W \frac{g^2|U_{N_\alpha \ell}|^2}{96\pi^2 C_\lambda^2} \left(\frac{M_N}{m_W}\right)^2 \left(\frac{m_W}{\Lambda}\right)^{2\Delta_N - 3} A_{\Delta_N - 1/2} f(\Delta_N, \frac{\mu_{IR}^2}{m_W^2})$$

Muon g-2



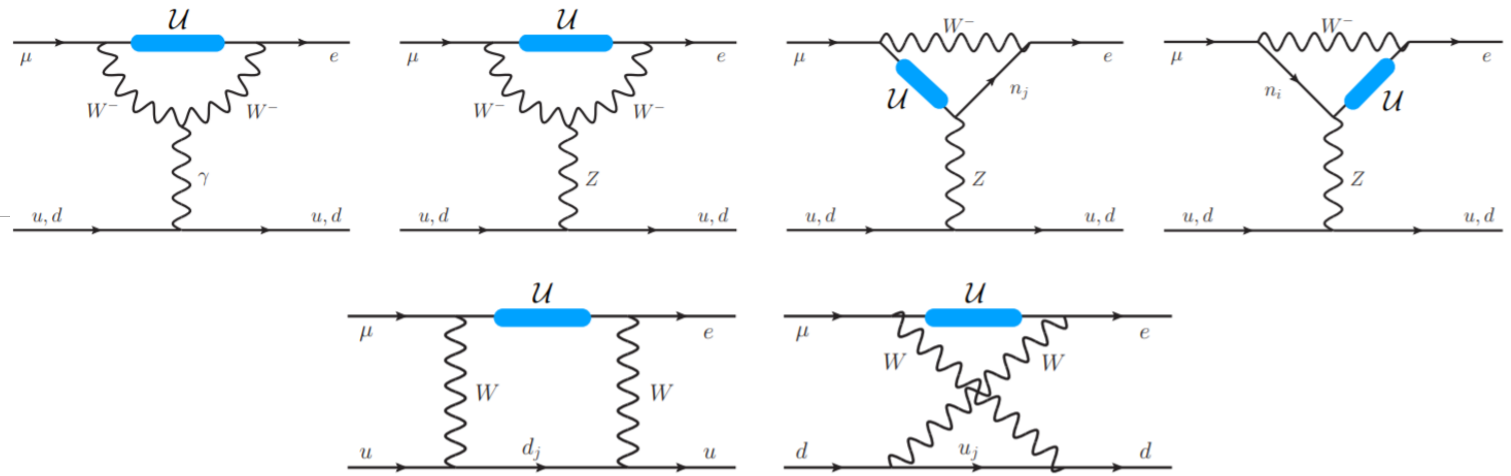


$$a_\mu^{\mathcal{U}} = -\sum_{\alpha=1}^{\mathcal{N}_N} \frac{G_F m_\mu^2}{16\sqrt{2}\pi^3} \left(\frac{|U_{N_\alpha \mu}|^2}{C_\lambda^2}\right) \left(\frac{M_W}{M_N}\right)^{2\Delta_N - 5} A_{\Delta_N - 1/2}$$

$$\int_{z_{IR}}^{\infty} dz\, (z^2 - z_{IR}^2)^{\Delta_N - 5/2} \left[\frac{2z^7 + 3z^5 - 6z^3 + z - 6z^5 \log(z^2)}{(z^2-1)^4}\right]$$

Complex but the contribution has a wrong sign in our minimal model.
Considering an equally well-motivated model with light vector composite states will fix this (in progress).

$\mu \to e$ & $0\nu\beta\beta$

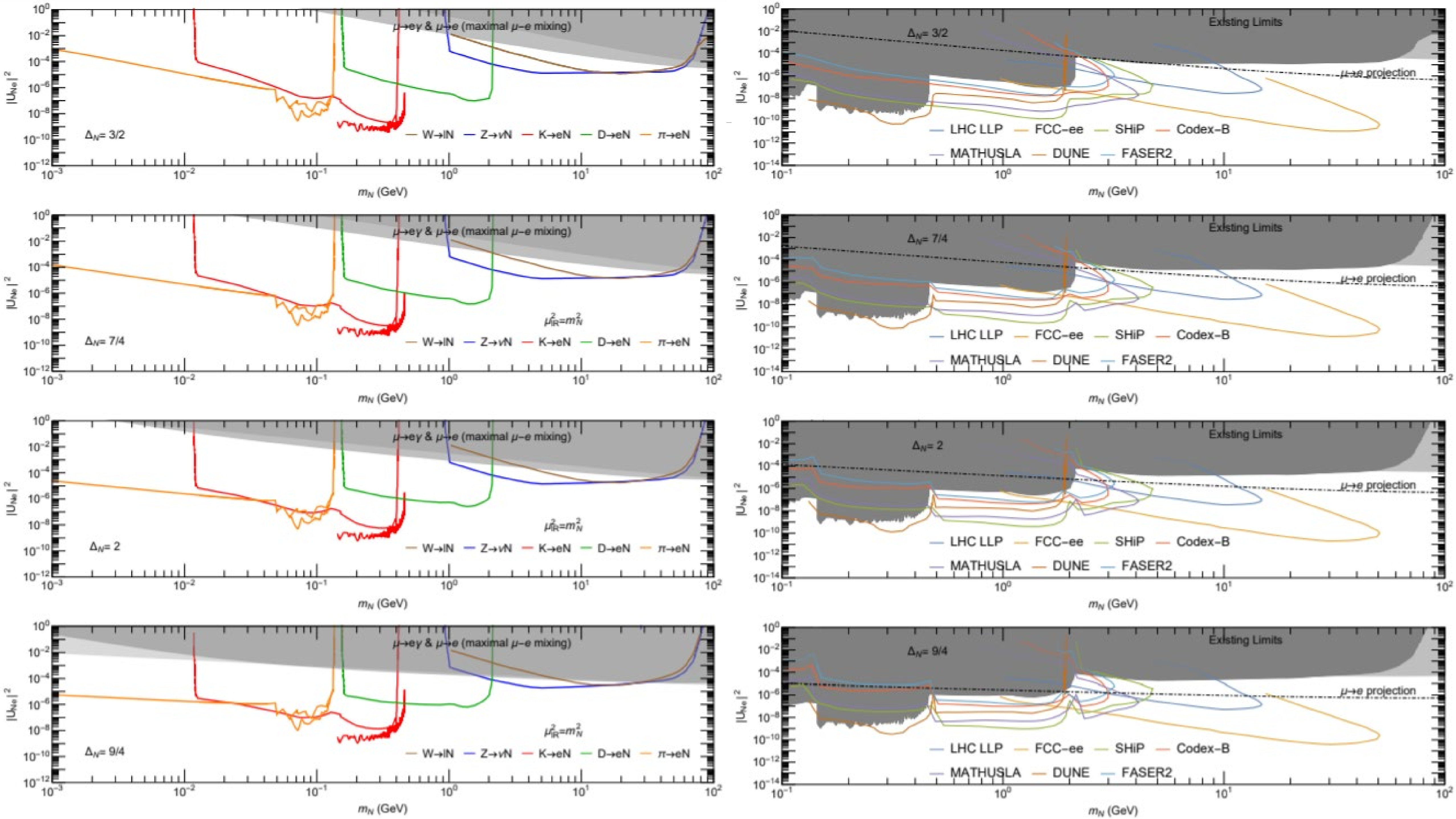


$$\mathcal{M}_N = \langle \nu(p) | T \left[\lambda L(x) H(x) N(x) \, \frac{\mu^c}{2} \, (N^c(y))^2 \;\; \lambda L(z) H(z) N(z) \right] | \nu(p) \rangle$$

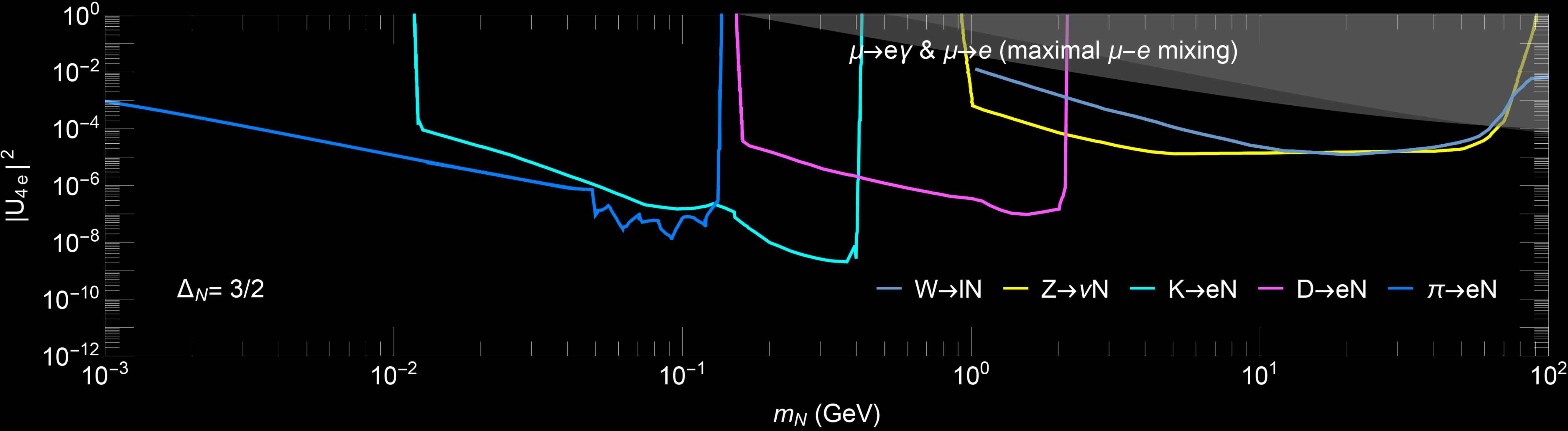
$$\widetilde{\mathcal{M}}_N = \langle \nu(p) | T \left[\lambda L(x) H(x) N(x) \, \frac{\mu}{2} N^{\dagger 2}(y) \; \lambda L(z) H(z) N(z) \right] | \nu(p) \rangle$$

$$\mathcal{M}_N \sim \frac{\lambda^2 v_{\rm EW}^2 \mu^c}{M_N^2} = m_\nu \qquad\qquad \mathcal{M}_N \sim \frac{\lambda^2 v_{\rm EW}^2 M_N^2 \mu^c}{p^4} = m_\nu \left(\frac{M_N}{p} \right)^4$$

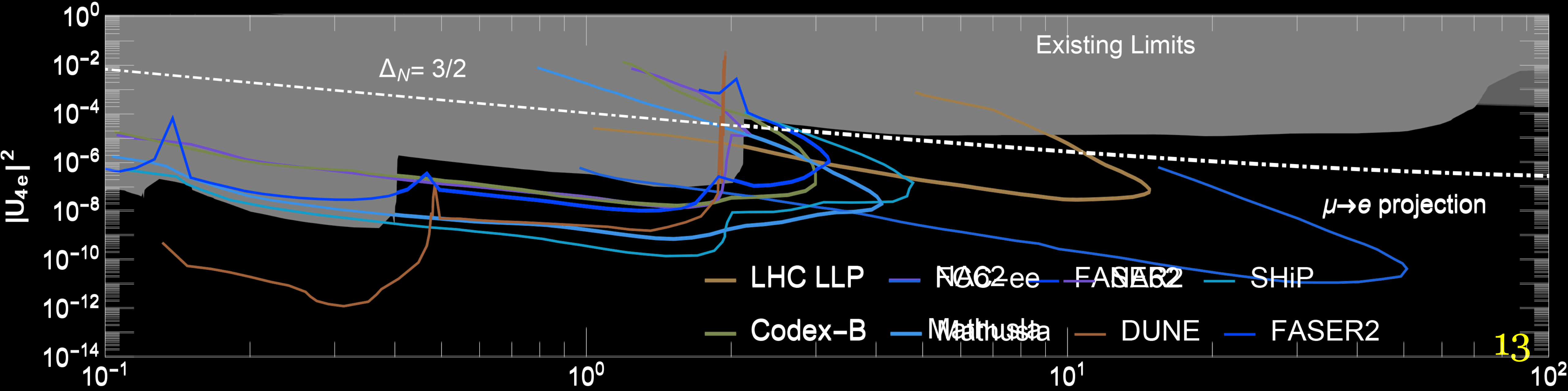
$$\widetilde{\mathcal{M}}_N \sim \frac{\lambda^2 v_{\rm EW}^2 \mu}{M_N^2} \frac{p^2}{M_N^2} = \frac{\mu}{\mu^c} \frac{p^2}{M_N^2} m_\nu \qquad\qquad \widetilde{\mathcal{M}}_N \sim \frac{\lambda^2 v_{\rm EW}^2 \mu}{p^2} = m_\nu \frac{\mu}{\mu^c} \left(\frac{M_N}{p} \right)^2$$

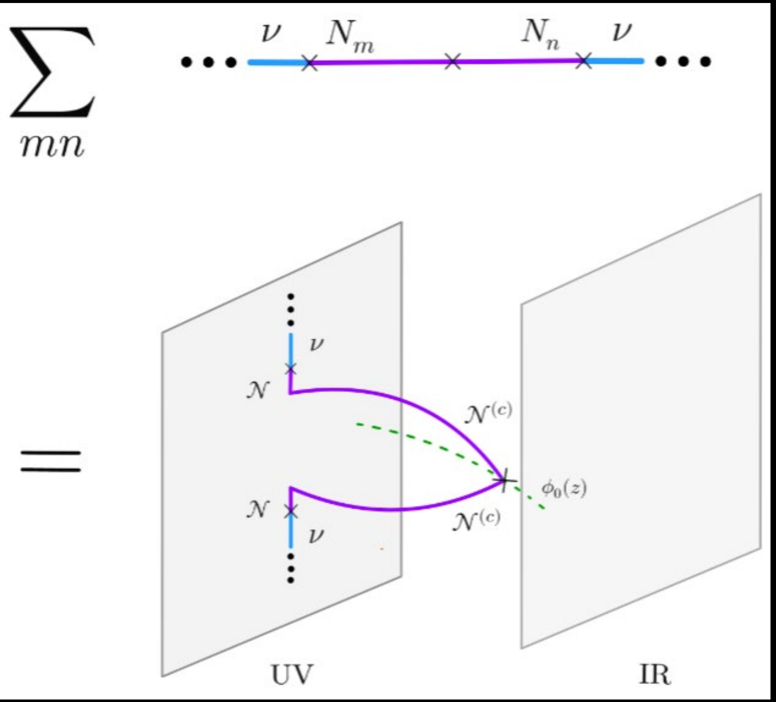


μ→eγ & μ→e (maximal μ−e mixing)
Δ_N= 3/2
W→lN
Z→νN
K→eN
D→eN
π→eN
$|U_{Ne}|^2$
m_N (GeV)
Existing Limits
μ→e projection
LHC LLP
FCC−ee
SHiP
Codex-B
MATHUSLA
DUNE
FASER2
Δ_N= 7/4
$\mu^2_{IR}=m^2_N$
Δ_N= 2
Δ_N= 9/4

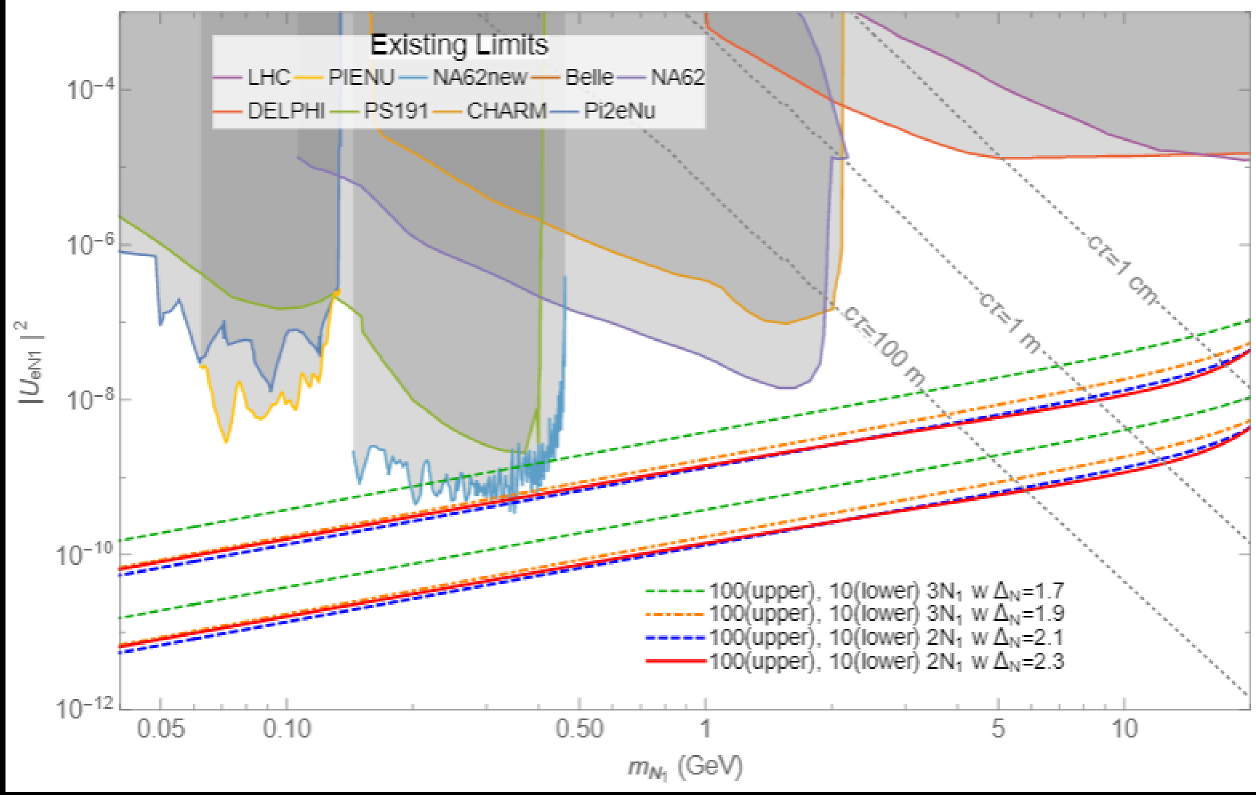


For instance, for Sterile Neutrinos





Chacko, Dev, ZL, Sanket, to appear



Thank you!