

Neutrino Masses from new Weinberg-like Operators

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Based on:

[JHEP 05 \(2024\) 055](#) [Alessio Giarnetti, Juan Herrero-Garcia, Simone Marciano, Davide Meloni, DV]

[arXiv: 2312.13356](#), [2312.14119](#)



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Gen—T

Neutrino masses

Usual Seesaws



Unique operator
at $d = 5$

Weinberg: PRL 43
(1979)

$$\mathcal{L}_5 = \frac{c_5}{\Lambda_{NP}} LLHH \xrightarrow[\langle H \rangle = v]{\text{EWSSB}} m_\nu \sim \frac{c_5}{\Lambda_{NP}} v^2 \gtrsim 0.05 \times 10^{-9} \text{ GeV}$$

$\lesssim 10^{14} \text{ GeV}$

174 GeV

UV completions at the tree level \rightarrow Usual Seesaws (SSI/II/III)

Difficult to probe this NP scale for neutrino masses and lepton number violation

Beyond the usual Seesaws

New Weinberg-like Operators

Augment SM by new SU(2) scalar multiplets → New operators

$$\mathcal{O}_5^{(1)} = (LH)_N(L\Phi_i)_N$$

$$\mathcal{O}_5^{(2)} = (L\Phi_i)_N(L\Phi_i)_N$$

$$\mathcal{O}_5^{(3)} = (L\Phi_i)_N(L\Phi_j)_N$$

New scalars take a VEV → $\langle \Phi_i \rangle = v_i$, $\langle \Phi_j \rangle = v_j$ → Can't be far from the EW scale

$$m_\nu \sim vv_i/\Lambda$$

$$m_\nu \sim v_i^2/\Lambda$$

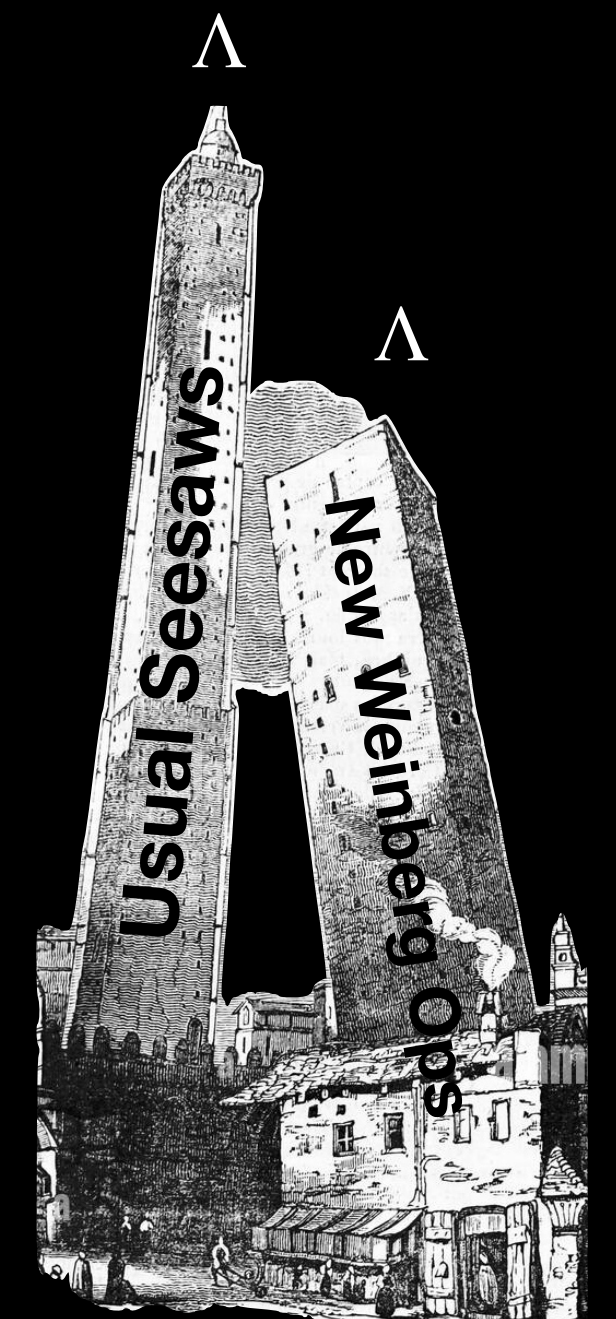
$$m_\nu \sim v_i v_j/\Lambda$$

ρ parameter: $\langle \Phi_{i,j} \rangle \ll \langle H \rangle$ → Λ is parametrically suppressed

Extra suppression possible from the WCs



Collider searches + EWPTs → More testable than the usual seesaws



Genuine Models

UV Completions

Do not generate the Weinberg operators with just the SM Higgs

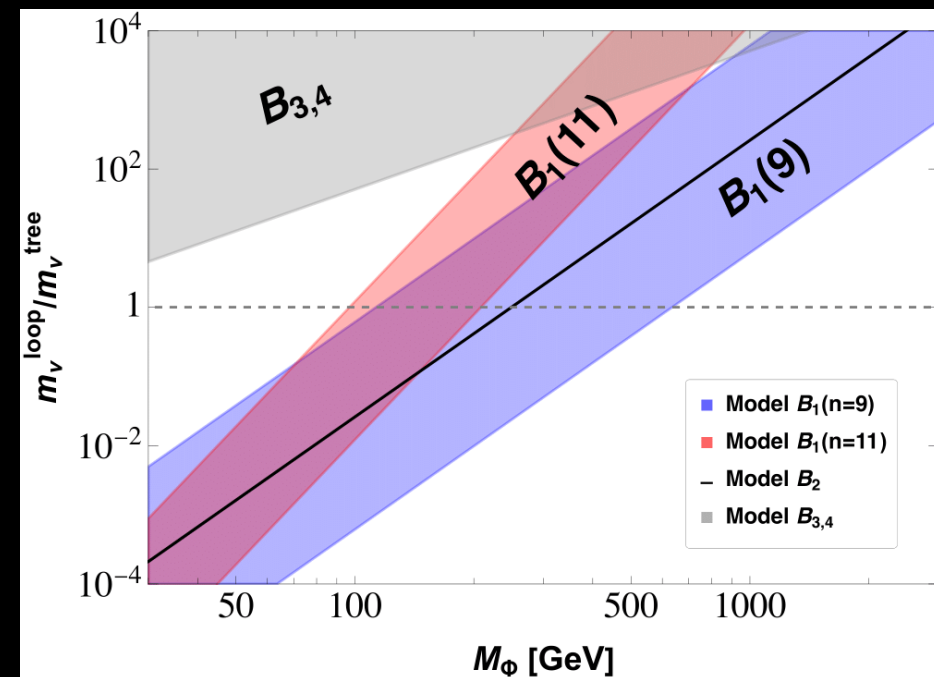
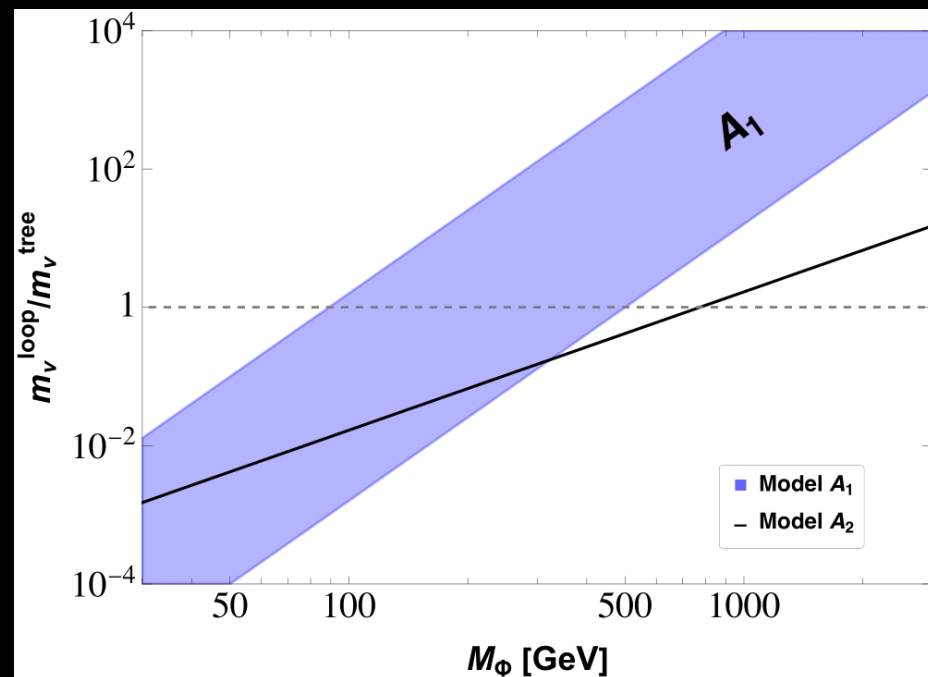
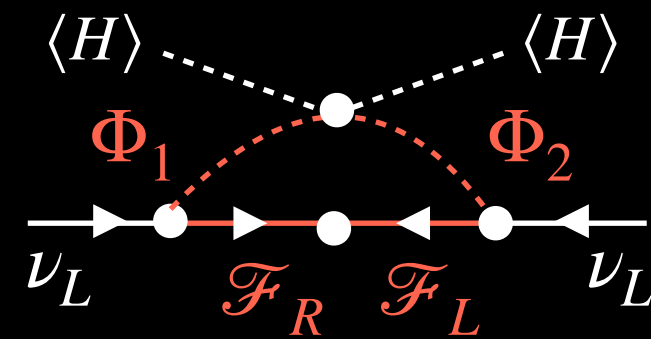
Model	Scalar Multiplets	Mediators	Op.	Wilson Coefficients
A₁	$\Phi_1 = 4_{-1/2}^S$	$\Sigma = 5_0^F$	$\mathcal{O}_5^{(2)}$	$C_5^{(2)} = y_1 M_\Sigma^{-1} y_1^T$
A₂	$\Phi_1 = 4_{-3/2}^S$	$\mathcal{F} = 3_{-1}^F$	$\mathcal{O}_5^{(1)}$	$C_5^{(1)} = y_1 M_{\mathcal{F}}^{-1} y_H^T + y_H M_{\mathcal{F}}^{-1} y_1^T$
B₁	$\Phi_1 = 4_{1/2}^S, \Phi_2 = 4_{-3/2}^S$	$\mathcal{F} = 5_{-1}^F$	$\mathcal{O}_5^{(3)}$	$C_5^{(3)} = y_1 M_{\mathcal{F}}^{-1} y_2^T + y_2 M_{\mathcal{F}}^{-1} y_1^T$
B₂	$\Phi_1 = 3_0^S, \Phi_2 = 5_{-1}^S$	$\mathcal{F} = 4_{-1/2}^F$	$\mathcal{O}_5^{(3)}$	$C_5^{(3)} = y_1 M_{\mathcal{F}}^{-1} y_2^T + y_2 M_{\mathcal{F}}^{-1} y_1^T$
B₃	$\Phi_1 = 5_{-2}^S, \Phi_2 = 5_1^S$	$\mathcal{F} = 4_{3/2}^F$	$\mathcal{O}_5^{(3)}$	$C_5^{(3)} = y_1 M_{\mathcal{F}}^{-1} y_2^T + y_2 M_{\mathcal{F}}^{-1} y_1^T$
B₄	$\Phi_1 = 5_{-1}^S, \Phi_2 = 5_0^S$	$\mathcal{F} = 4_{1/2}^F$	$\mathcal{O}_5^{(3)}$	$C_5^{(3)} = y_1 M_{\mathcal{F}}^{-1} y_2^T + y_2 M_{\mathcal{F}}^{-1} y_1^T$

Kumericki, Picek, Radovic (2012); Babu, Nandi, Tavartkiladze (2009); McDonald (2013);
Bonnet, Hernandez, Ota, Winter (2009); Cepedello, Hirsch, Helo (2018)

Genuine Models

Loop Contribution

$$(m_\nu)_{\alpha\beta}^{\text{loop}} \propto \lambda'' \frac{v^2}{8\pi^2 M_{\mathcal{F}}} (y_1 y_2^T + y_2 y_1^T)_{\alpha\beta}$$



$\mathbb{Z}_2/U(1) \rightarrow m_\nu$ at one loop only,
no tree contribution

(Generalised) Scotogenic models \rightarrow Minimal
DM Candidates $\mathcal{O}(1 - 10)$ TeV

Low-scale variants

A1: Majorana mass \rightarrow Inverse seesaw $M_{\mathcal{F}} \simeq \mathcal{O}(1)$ TeV

A2: Hierarchy among Yukawas/VEVs: $y_1 v_1 \ll y_H v$

$$y_H \simeq 1 \rightarrow \left(\frac{y_1}{10^{-10}} \right) \left(\frac{v_1}{\text{GeV}} \right) \simeq 1$$

Bi: $y_1 v_1 \ll y_2 v_2 \rightarrow$ Rich phenomenology from Φ_2

Significant Yukawas \rightarrow Large contribution to $D = 6$

$$\mathcal{O}_6 = \left(\bar{L}_\alpha \tilde{\phi}_1 \right) i\gamma_\mu D^\mu \left(\tilde{\phi}_1^\dagger L_\beta \right) \Rightarrow \left(y_1 \frac{v_1^2}{M_{\mathcal{F}}^2} y_1^\dagger \right)_{\alpha\beta} \lesssim \mathcal{O}(10^{-3})$$

LFV, Non-unitary PMNS, FCNCs, Universality violation

Conclusions

More details and phenomenological implications

New scalar multiplets at EW scale → **New Weinberg-like operators**

New scalar VEVs suppressed → **Neutrino masses can be generated for lower LNV scales**

EW scalars → **Production at colliders, contribution to W-boson mass**

Collider signatures → **SS2L, SS3L, SS4L, LNV + LFV events**

Small VEVs ($\lesssim \mathcal{O}(100)$ keV) → **Neutrino mass matrix can be reconstructed from doubly charged-scalars decays**

Neutrino Masses from new Weinberg-like Operators

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INTRODUCTION

EWSSB: $\mathcal{L}_5 = \frac{c_5}{\Lambda_{NP}} LLHH \rightarrow \langle H \rangle = v \rightarrow m_\nu \sim \frac{c_5}{\Lambda_{NP}} v^2 \gtrsim 0.05$ eV

Tree level UV Completions → Usual Seesaws

Type I: $(H) \rightarrow (H) \rightarrow (H)$
Type II: $(H) \rightarrow (H) \rightarrow (H)$
Type III: $(H) \rightarrow (H) \rightarrow (H)$

Λ_{NP} close to GUT scale, very difficult to test → Need more testable models

NEW OPERATORS

New scalars at EW scale → New Weinberg-like operators

$\mathcal{O}_s^{(1)} = LL\Phi\Phi_i$, $\mathcal{O}_s^{(2)} = LL\Phi_i\Phi_j$, $\mathcal{O}_s^{(3)} = LL\Phi_i\Phi_j$

$m_\nu \sim v v_i/\Lambda$, $m_\nu \sim v_i^2/\Lambda$, $m_\nu \sim v_i v_j/\Lambda$

ρ parameter: $(\Phi_{i,j}) \equiv v_{i,j} \lesssim \mathcal{O}(1)$ GeV $\ll (H)$
→ Λ is parametrically suppressed

Extra suppression possible from the WCs
More testable than the usual seesaws

GENUINE MODELS

Do not generate usual seesaws + $m_\nu \propto v_{i,j}$
Interesting UV completions → Fermionic mediators
Majorana (Σ) for $\Phi_i = \Phi_j$ or Vector-like (\mathcal{F}) for $\Phi_i \neq \Phi_j$

Model	Scalar Multiplets	Mediators	Op.
A1	$\Phi_1 = 4_{-1/2}^0$	$\Sigma = S_6^0$	$\mathcal{O}_s^{(2)}$
A2	$\Phi_1 = 4_{-1/2}^0$	$\mathcal{F} = 3_{-1}^0$	$\mathcal{O}_s^{(1)}$
B1	$\Phi_1 = 4_{1/2}^0, \Phi_2 = 4_{-1/2}^0$	$\mathcal{F} = S_{-1}^0$	$\mathcal{O}_s^{(3)}$
B2	$\Phi_1 = 3_0^0, \Phi_2 = S_{-1}^0$	$\mathcal{F} = 4_{-1/2}^0$	$\mathcal{O}_s^{(3)}$
B3	$\Phi_1 = S_{-2}^0, \Phi_2 = S_1^0$	$\mathcal{F} = 4_{-1/2}^0$	$\mathcal{O}_s^{(3)}$
B4	$\Phi_1 = S_{-1}^0, \Phi_2 = S_0^0$	$\mathcal{F} = 4_{-1/2}^0$	$\mathcal{O}_s^{(3)}$

INDUCED VEVS

VEVs induced by the Higgs → Naturally suppressed for $M_\Phi \gg v$

$\mu \Phi_i H^2$, $\lambda \Phi_i H^3$, $\lambda' \Phi_i \Phi_j H^2$

$v_i \approx \mu \frac{v^2}{2M_\Phi^2}$, $v_i \approx \lambda \frac{v^3}{2M_\Phi^3}$, $v_j \approx \lambda' v \frac{v^2}{2M_\Phi^2}$

Integrate out the heavy scalars → Higher dimensional operators

$\frac{c_n^{(0)}}{\Lambda^{n-4}} LLHH(H^\dagger H)^{n-2}$

LOOP CONTRIBUTION

$(m_\nu)_{\text{loop}}^{ij} \propto \lambda^2 \frac{v^2}{8\pi^2 M_\Phi^2} (y_1 y_1^j + y_2 y_1^j)_{\text{op}}$

$\lambda \in [0, 1, 1]$

$Z_2/U(1) \rightarrow m_\nu$ at one loop only, no tree contribution
(Generalised) Scotogenic models → Minimal DM Candidates $\mathcal{O}(1 - 10)$ TeV

COLLIDER SIGNATURES

$\Phi^{\pm\pm} \rightarrow 2l^\pm 2W^\pm, \Phi^{\pm\pm} \rightarrow 2l^\pm W^\pm 3W^\pm, \Phi^{\pm\pm} \rightarrow 2l^\pm 2W^\pm 4W^\pm$

Multi-lepton events → SS2L, SS3L, SS4L

Observation of $l^\pm l^\pm W^\mp W^\mp$ events → Experimental evidence of LNV
Elements of $(m_\nu)_{ij} \rightarrow$ LFV 4-lepton events $l_i^\pm l_j^\pm l_k^\mp l_l^\mp$; $l_i^\pm l_j^\pm l_k^\mp l_l^\mp (i \neq j)$

LOW-SCALE VARIANTS

A1: Majorana mass → Inverse seesaw
A2: Hierarchy among Yukawas/VEVs: $y_1 v_1 \ll y_H v$

$y_H \approx 1 \rightarrow \left(\frac{y_1}{10^{-10}}\right) \left(\frac{v_1}{\text{GeV}}\right) \approx 1$ $M_\Phi \approx \mathcal{O}(1)$ TeV

B1: $y_1 v_1 \ll y_2 v_2 \rightarrow$ Rich phenomenology from Φ_2
Significant Yukawas → Large contribution to $D \approx 6$ operators

$\mathcal{O}_6 = \left(\bar{l}_\alpha \tilde{\Phi}_1\right) \nu_R D^\mu \left(\tilde{\Phi}_2 l_\beta\right) \Rightarrow \left(y_1 \frac{v_1^2}{M_\Phi^2} y_2^i\right)_{\text{op}} \lesssim \mathcal{O}(10^{-3})$

CONCLUSIONS

New SU(2) scalar multiplets at EW scale may be the origin on m_ν
New VEVs suppressed → m_ν can be generated for lower LNV scales
EW scalars → Production at colliders, contribution to W-boson mass
Small VEVs ($\lesssim \mathcal{O}(100)$ keV) → Neutrino mass matrix can be reconstructed from doubly charged scalar decays
Low-scale models → LFV, Non-unitarity, FCNCs, Scotogenic models

REFERENCES

A. Giarnetti, J. Herrero-García, S. Marciano, D. Meloni and D. Vatsyayan, *Neutrino masses from new Weinberg-like operators: Phenomenology of TeV scalar multiplets*, JHEP 05 (2024) 055 [2312.13356]

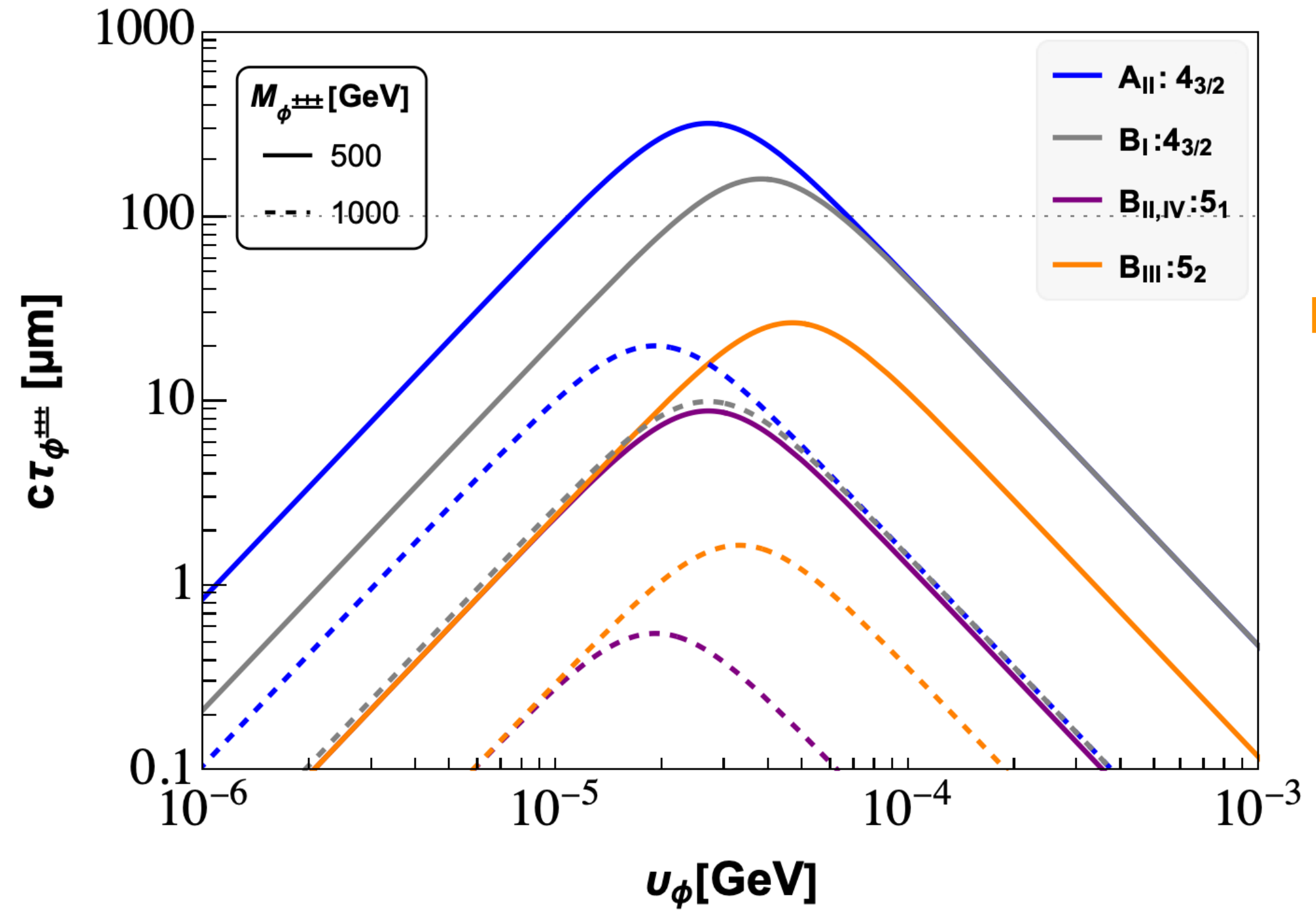
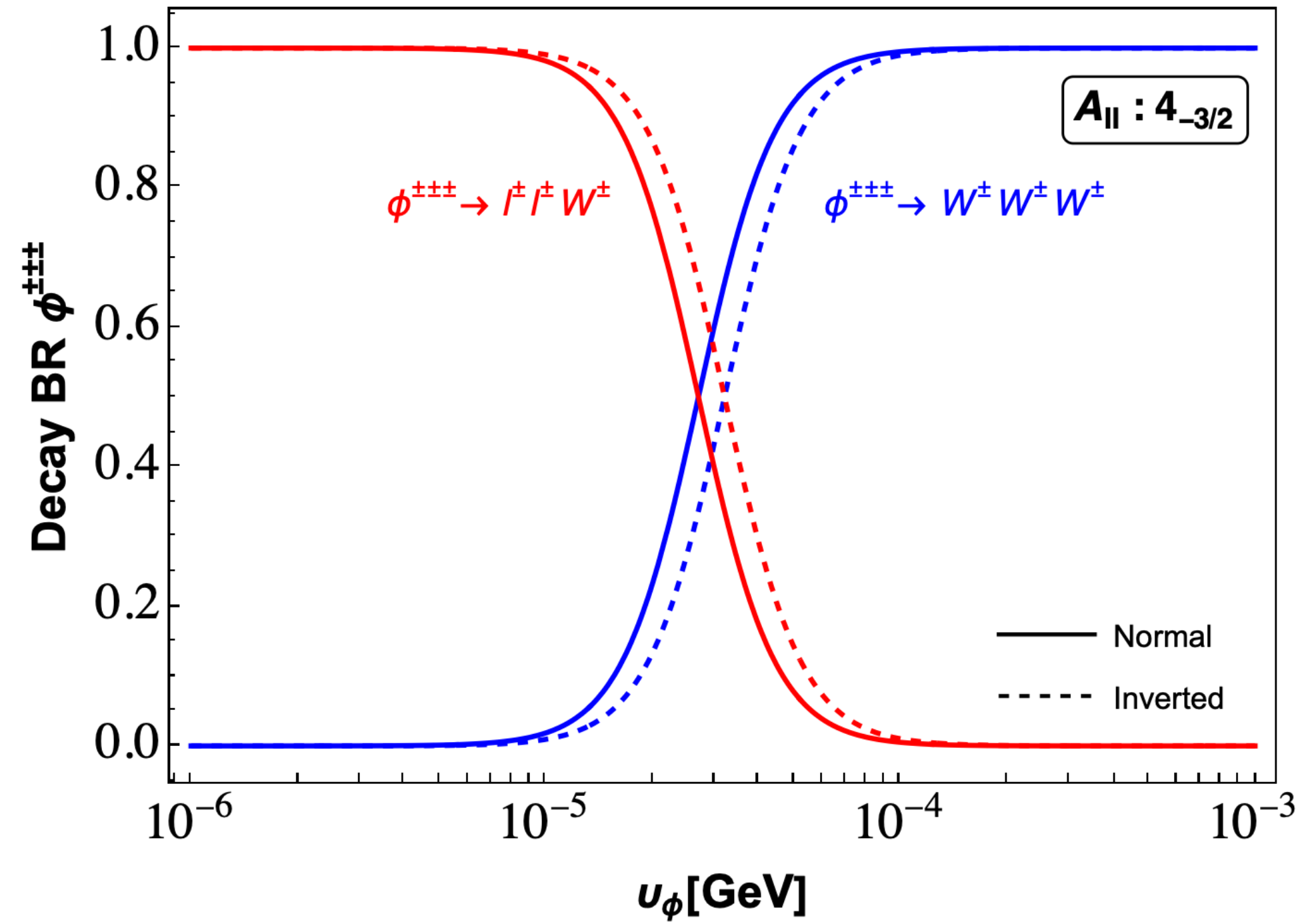
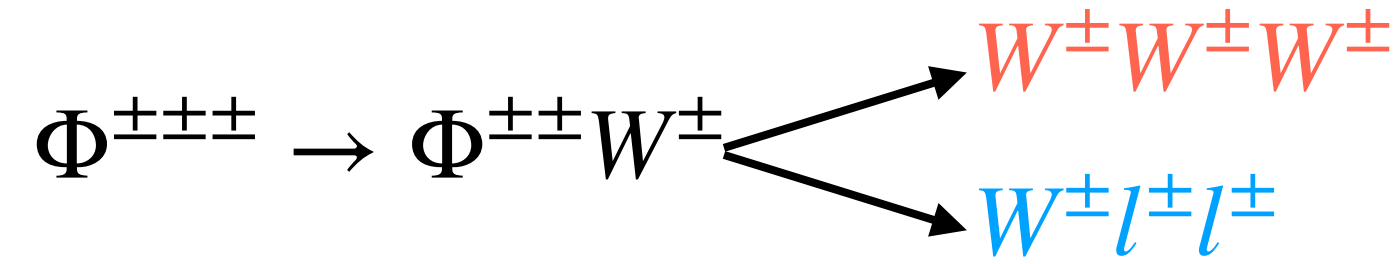
A. Giarnetti, J. Herrero-García, S. Marciano, D. Meloni and D. Vatsyayan, *Neutrino masses from new seesaw models: Low-scale variants and phenomenological implications*, [2312.14119]

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Backup

Collider Phenomenology

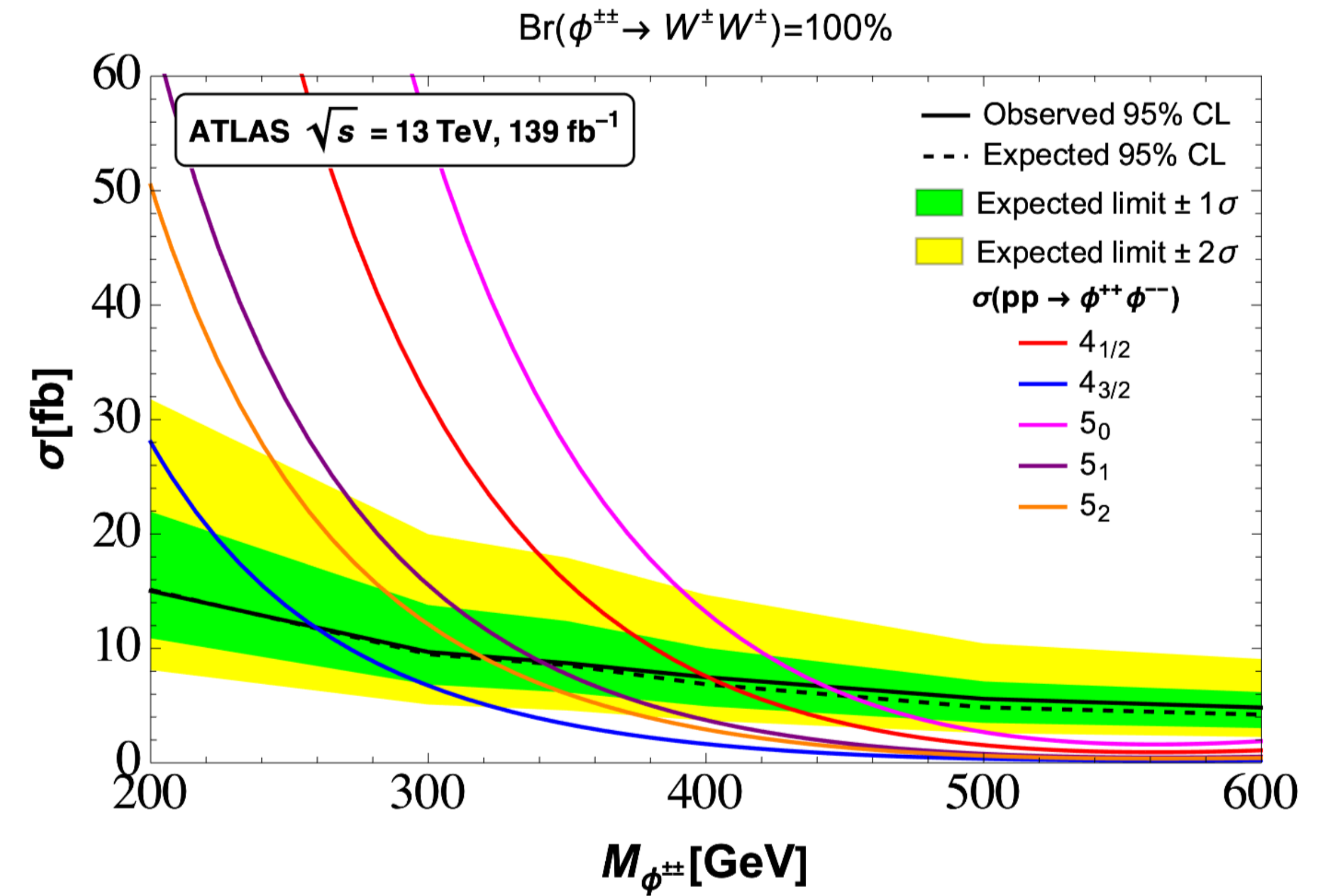
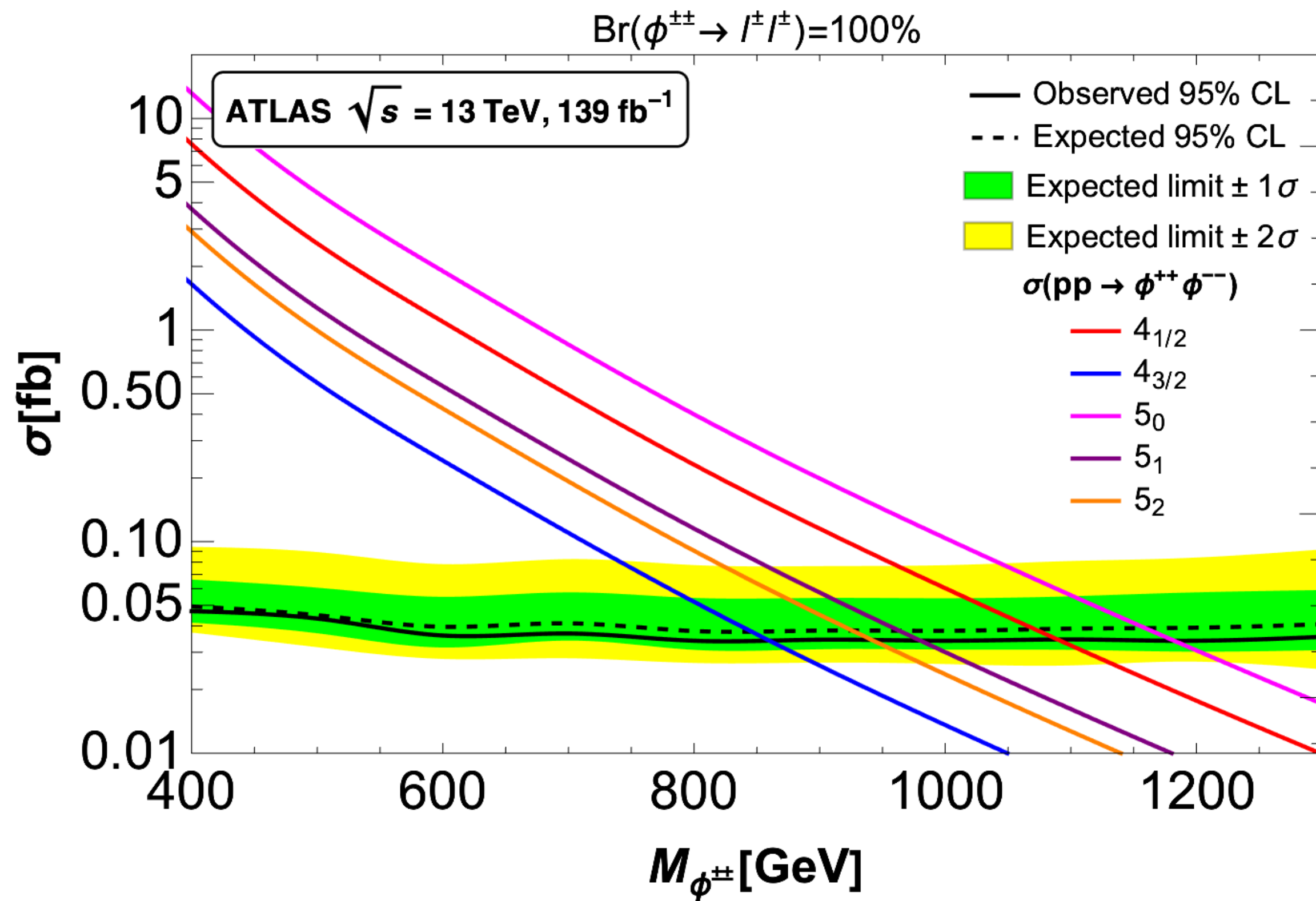
Triply-charged scalar decays



May lead to Displaced vertices

Collider Phenomenology

Searches



Phenomenology

LFV Constraints

Model	Yukawa combination	Upper limits		
		$\alpha\beta = \mu e$	$\alpha\beta = \tau e$	$\alpha\beta = \tau\mu$
A₁	$ y_1^{\beta*} y_1^\alpha (\text{TeV}/M_\Sigma)^2$	< 0.0002	< 0.13	< 0.16
A₂	$ y_1^{\beta*} y_1^\alpha (\text{TeV}/M_{\mathcal{F}})^2$	< 0.0004	< 0.24	< 0.28
B₁	$ y_1^{\beta*} y_1^\alpha - 0.5 y_2^{\beta*} y_2^\alpha (\text{TeV}/M_{\mathcal{F}})^2$	< 0.0004	< 0.29	< 0.34
B₂	$ y_1^{\beta*} y_1^\alpha - 50 y_2^{\beta*} y_2^\alpha (\text{TeV}/M_{\mathcal{F}})^2$	< 0.0011	< 0.72	< 0.84
B₃	$ y_1^{\beta*} y_1^\alpha - 2.12 y_2^{\beta*} y_2^\alpha (\text{TeV}/M_{\mathcal{F}})^2$	< 0.0002	< 0.15	< 0.18
B₄	$ y_1^{\beta*} y_1^\alpha + 6.6 y_2^{\beta*} y_2^\alpha (\text{TeV}/M_{\mathcal{F}})^2$	< 0.0004	< 0.24	< 0.28

Scotogenic/Generalised Scotogenic Models

DM Candidates

Model	New fields	Sym.	DM candidates	DM Mass (TeV)
\mathbf{A}'_1	$\Phi_1 = 4^S_{-1/2}, \Sigma = 5^F_0$	Z_2	$4^S_{-1/2}, 5^F_0$	$M_{\Phi_1} \approx 3.2, M_{\Sigma} \approx 10$
\mathbf{A}'_2	$\Phi_1 = 4^S_{-3/2}, \mathcal{F} = 3^F_{-1}$	—	—	—
\mathbf{B}'_1	$\Phi_1 = 4^S_{1/2}, \Phi_2 = 4^S_{-3/2}, \mathcal{F} = 5^F_{-1}$	$U(1)$	$4^S_{1/2}, 4^S_{-3/2}$	$M_{\Phi_1} \approx 3.2, M_{\Phi_2} \approx 3.5$
\mathbf{B}'_2	$\Phi_1 = 3^S_0, \Phi_2 = 5^S_{-1}, \mathcal{F} = 4^F_{-1/2}$	$U(1)$	$3^S_0, 5^S_{-1}$	$M_{\Phi_1} \approx 2.5, M_{\Phi_2} \approx 3.4$
\mathbf{B}'_3	$\Phi_1 = 5^S_{-2}, \Phi_2 = 5^S_1, \mathcal{F} = 4^F_{3/2}$	$U(1)$	$5^S_{-2}, 5^S_1$	$M_{\Phi_1} \approx 3.9, M_{\Phi_2} \approx 3.4$
\mathbf{B}'_4	$\Phi_1 = 5^S_{-1}, \Phi_2 = 5^S_0, \mathcal{F} = 4^F_{1/2}$	$U(1)$	$5^S_{-1}, 5^S_0$	$M_{\Phi_1} \approx 3.4, M_{\Phi_2} \approx 9.4$

List of (*Generalised*) *Scotogenic*-like models which generate neutrino masses at one loop. We give the stabilising symmetry in the third column and the possible DM candidates in the fourth column. The mass for the DM candidate that reproduces the observed relic abundance is listed in the last column, including non-perturbative effects for the $Y = 0$ candidates