Dynamical Minimal Flavour Violating Inverse Seesaw

Fernando Arias Aragón

Based on: 2204.04672,
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Fundamentals and Motivation

Low Scale Seesaws and

Minimal Lepton Flavour Violation

Low Scale Seesaws

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- Neutrino masses require New Physics: Seesaw Mechanism

Mohapatra and Senjanovic. PRD 23 (1981) 165
Lazarides, Shafi and Wetterich, NPB 181 (1981) 287-300
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Inverse　　Linear

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Dinamical Inverse Seesaw in MFV

Setup, Phenomenology and

Impact of the CDF Measurement of M_W

Dynamical ISS in MFV – Setup

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$$x_u - x_Q = 0, \qquad x_d - x_u \simeq \log_\varepsilon \frac{m_b}{m_t}, \qquad x_e - x_\ell \simeq \log_\varepsilon \frac{m_\tau}{m_t} \qquad x_d - x_u = x_e - x_\ell = \begin{cases} 1 & \text{for} \quad \varepsilon = 0.01\,, \\ 3 & \text{for} \quad \varepsilon = 0.23\,, \end{cases}$$

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- Three scenarios:

CASE A

$$\mathcal{G}_F^{\text{NA}} = SU(3)_{\ell_L} \times SU(3)_{e_R} \times SO(3)_{N_R+S_R}$$

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$$x_u - x_Q = 0, \qquad x_d - x_u \simeq \log_\varepsilon \frac{m_b}{m_t}, \qquad x_e - x_\ell \simeq \log_\varepsilon \frac{m_\tau}{m_t}$$

$$x_d - x_u = x_e - x_\ell = \begin{cases} 1 & \text{for} \quad \varepsilon = 0.01\,, \\ 3 & \text{for} \quad \varepsilon = 0.23\,, \end{cases}$$

- Three scenarios:

CASE A

$$\mathcal{G}_F^{\rm NA} = SU(3)_{\ell_L} \times SU(3)_{e_R} \times SO(3)_{N_R+S_R}$$

$\mu,\ \mu',\ \Lambda \propto \mathbb{1}$ $\qquad \mathcal{Y}_\nu \sim \mathcal{Y}'_\nu \sim (\mathbf{3}, 1, \overline{\mathbf{3}})$

CASE B

$$\mathcal{G}_F^{\rm NA} = SU(3)_V \times SU(3)_{e_R}$$

$N_R, S_R \sim (\mathbf{3}, 1)$

$\mathcal{Y}_\nu,\ \mathcal{Y}'_\nu \propto \mathbb{1}$ $\qquad \mu \sim \mu' \sim \Lambda \sim (\overline{\mathbf{6}}, 1)$

Dynamical ISS in MFV – Setup

- Froggatt-Nielsen + MFV: $U(1)_{FN} \equiv U(1)_{PQ} \supset \mathcal{G}_F$ **FAA**, L. Merlo, 1709.07039
- Flavon Φ introduced for PQ invariance, $x_\Phi = -1$

$$\mathcal{L}_Y \supset y_\psi \, \bar{\psi}_L H \psi_R \left(\frac{\Phi}{\Lambda_\Phi}\right)^{x_{\psi_R} - x_{\psi_L}}, \qquad \varepsilon \equiv \frac{v_\Phi}{\sqrt{2}\Lambda_\Phi}, \qquad m_\psi = y_\psi \frac{v}{\sqrt{2}} \varepsilon^{x_{\psi_R} - x_{\psi_L}}$$

$$x_u - x_Q = 0, \qquad x_d - x_u \simeq \log_\varepsilon \frac{m_b}{m_t}, \qquad x_e - x_\ell \simeq \log_\varepsilon \frac{m_\tau}{m_t}$$

$$x_d - x_u = x_e - x_\ell = \begin{cases} 1 & \text{for} \quad \varepsilon = 0.01\,, \\ 3 & \text{for} \quad \varepsilon = 0.23\,, \end{cases}$$

- Three scenarios:

CASE A	CASE B	CASE C
$\mathcal{G}_F^{\rm NA} = SU(3)_{\ell_L} \times SU(3)_{e_R} \times SO(3)_{N_R+S_R}$	$\mathcal{G}_F^{\rm NA} = SU(3)_V \times SU(3)_{e_R}$	$\mathcal{G}_F^{\rm NA} = SU(3)_V \times SU(3)_{e_R}$
$\mu,\ \mu',\ \Lambda \propto \mathbb{1}$ $\quad \mathcal{Y}_\nu \sim \mathcal{Y}'_\nu \sim (\mathbf{3}, 1, \bar{\mathbf{3}})$	$N_R, S_R \sim (\mathbf{3}, 1)$	$N_R \sim (\mathbf{3}, 1), \bar{S}_R \sim (\mathbf{3}, 1)$
	$\mathcal{Y}_\nu,\ \mathcal{Y}'_\nu \propto \mathbb{1}$ $\quad \mu \sim \mu' \sim \Lambda \sim (\bar{\mathbf{6}}, 1)$	$\mathcal{Y}_\nu,\ \Lambda \propto \mathbb{1}$ $\quad \mu' \sim \mathcal{Y}'^\dagger_\nu \sim \mu^\dagger \sim (\bar{\mathbf{6}}, 1)$

Dynamical ISS in MFV – Case A

$$\mathcal{G}_F^{\mathrm{NA}} = SU(3)_{\ell_L} \times SU(3)_{e_R} \times SO(3)_{N_R+S_R}$$

Dynamical ISS in MFV – Case A

$$\mathcal{G}_F^{\rm NA} = SU(3)_{\ell_L} \times SU(3)_{e_R} \times SO(3)_{N_R+S_R}$$

$$-\mathscr{L}_Y^{\rm A} = \overline{\ell_L} H Y_e e_R \left(\frac{\Phi}{\Lambda_\Phi}\right)^{x_e - x_\ell} + \overline{\ell_L}\widetilde{H} Y_\nu N_R + c_\nu \overline{\ell_L}\widetilde{H} Y_\nu S_R \left(\frac{\Phi}{\Lambda_\Phi}\right)^{2x_\ell} + \\ + \frac{1}{2} c_N \overline{N_R^c} N_R \Phi \left(\frac{\Phi}{\Lambda_\Phi}\right)^{2x_\ell - 1} + \frac{1}{2} c_S \overline{S_R^c} S_R \Phi^\dagger \left(\frac{\Phi^\dagger}{\Lambda_\Phi}\right)^{2x_\ell - 1} + \Lambda \overline{N_R^c} S_R + \text{h.c.}$$

$$\mathcal{M}_\chi = \begin{pmatrix} 0 & \frac{v}{\sqrt{2}} Y_\nu & c_\nu \frac{v}{\sqrt{2}} \varepsilon^{2x_\ell} Y_\nu \\ \frac{v}{\sqrt{2}} Y_\nu^T & c_N \frac{v_\Phi}{\sqrt{2}} \varepsilon^{2x_\ell - 1} & \Lambda \\ c_\nu \frac{v}{\sqrt{2}} \varepsilon^{2x_\ell} Y_\nu^T & \Lambda & c_S \frac{v_\Phi}{\sqrt{2}} \varepsilon^{2x_\ell - 1} \end{pmatrix}$$

Dynamical ISS in MFV – Case A

$$\mathcal{G}_F^{\rm NA} = SU(3)_{\ell_L} \times SU(3)_{e_R} \times SO(3)_{N_R+S_R}$$

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$$\mathcal{M}_\chi = \begin{pmatrix} 0 & \frac{v}{\sqrt{2}} Y_\nu & c_\nu \frac{v}{\sqrt{2}} \varepsilon^{2x_\ell} \boxed{Y_\nu} \\ \frac{v}{\sqrt{2}} Y_\nu^T & c_N \frac{v_\Phi}{\sqrt{2}} \varepsilon^{2x_\ell - 1} & \Lambda \\ c_\nu \frac{v}{\sqrt{2}} \varepsilon^{2x_\ell} Y_\nu^T & \Lambda & c_S \frac{v_\Phi}{\sqrt{2}} \varepsilon^{2x_\ell - 1} \end{pmatrix}$$

Dynamical ISS in MFV – Case A

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Dynamical ISS in MFV – Case A

$$\mathcal{G}_F^{\rm NA} = SU(3)_{\ell_L} \times SU(3)_{e_R} \times SO(3)_{N_R+S_R}$$

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Dynamical ISS in MFV – Case A

$$\mathcal{G}_F^{\rm NA} = SU(3)_{\ell_L} \times SU(3)_{e_R} \times SO(3)_{N_R+S_R}$$

$$-\mathscr{L}_Y^{\rm A} = \overline{\ell_L} H Y_e e_R \left(\frac{\Phi}{\Lambda_\Phi}\right)^{x_e - x_\ell} + \overline{\ell_L}\widetilde{H} Y_\nu N_R + c_\nu \overline{\ell_L}\widetilde{H} Y_\nu S_R \left(\frac{\Phi}{\Lambda_\Phi}\right)^{2x_\ell} + \\ + \frac{1}{2} c_N \overline{N_R^c} N_R \Phi \left(\frac{\Phi}{\Lambda_\Phi}\right)^{2x_\ell - 1} + \frac{1}{2} c_S \overline{S_R^c} S_R \Phi^\dagger \left(\frac{\Phi^\dagger}{\Lambda_\Phi}\right)^{2x_\ell - 1} + \Lambda \overline{N_R^c} S_R + \text{h.c.}$$

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Dynamical ISS in MFV – Case A

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$$Y_\nu = \frac{1}{f^{1/2}} U \widehat{m}_\nu^{1/2} \mathcal{H}^T$$

$$U \equiv R_{23}(\theta_{23}) \cdot R_{13}(\theta_{13},\, \delta_{\rm CP}) \cdot R_{12}(\theta_{12}) \cdot \texttt{diag}\left(1,\, e^{i\,\alpha_2},\, e^{i\,\alpha_3}\right)$$

$$f \equiv \frac{v^2\, \varepsilon^{2x_\ell - 1}}{2\sqrt{2}\,\Lambda^2} \left(c_S\, v_\Phi - 2\sqrt{2}\, c_\nu\, \varepsilon\, \Lambda\right)$$

$$\mathcal{H} \equiv e^{i\phi} = \mathbb{1} - \frac{\cosh r - 1}{r^2}\phi^2 + i\frac{\sinh r}{r}\phi$$

$$M_N \simeq \Lambda$$

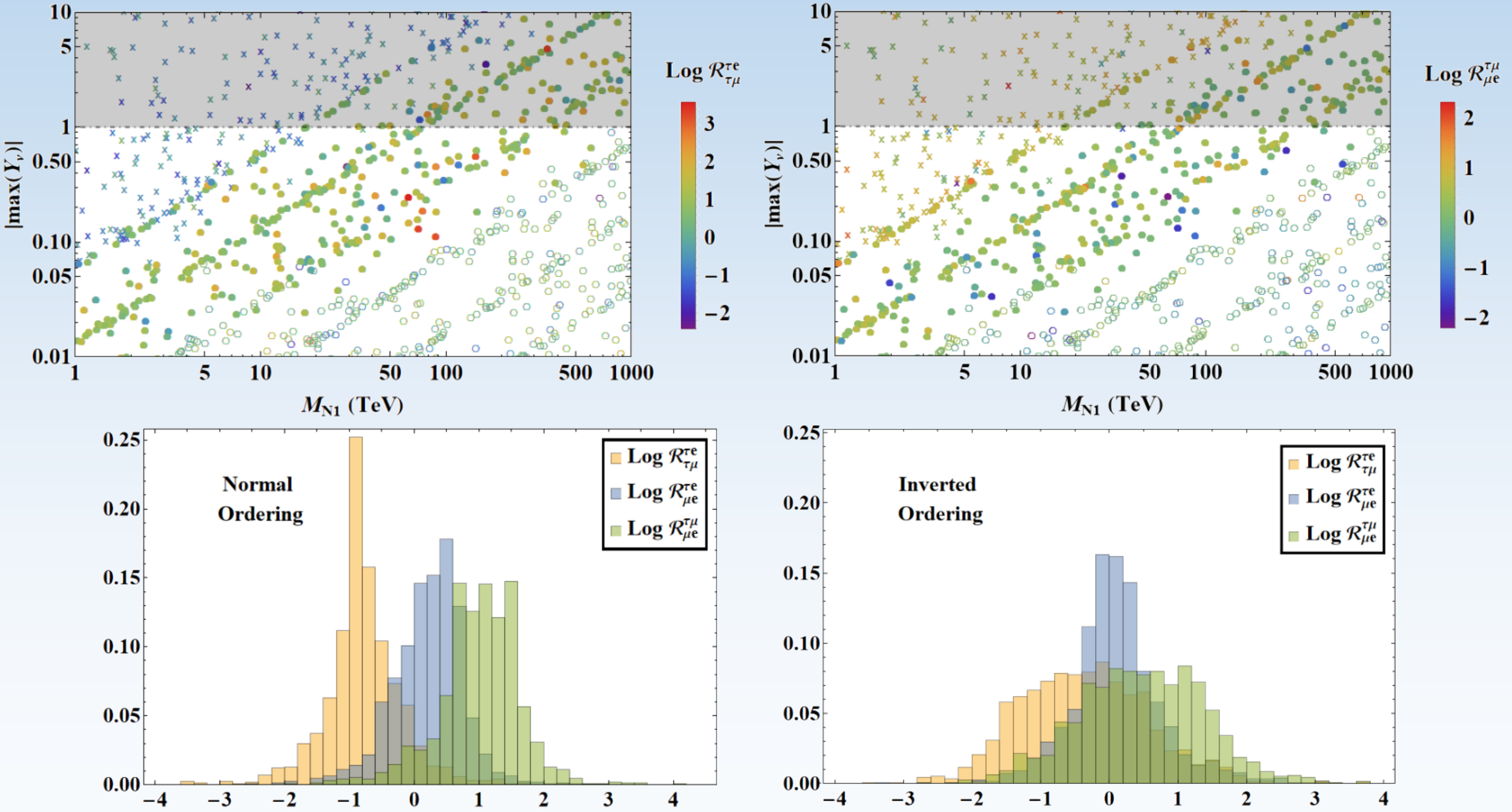
$$\phi = \begin{pmatrix} 0 & \phi_1 & \phi_2 \\ -\phi_1 & 0 & \phi_3 \\ -\phi_2 & -\phi_3 & 0 \end{pmatrix} \qquad r \equiv \sqrt{\phi_1^2 + \phi_2^2 + \phi_3^2}$$

Dynamical ISS in MFV – Case A

$$\mathcal{N} = (\mathbb{1} - \eta)\, U \qquad \eta = \frac{v^2}{4f\Lambda^2} U\, \widehat{m}_\nu^{1/2}\, \mathcal{H}^T\, \mathcal{H}^*\, \widehat{m}_\nu^{1/2}\, U^\dagger$$

Dynamical ISS in MFV – Case A

$$\mathcal{N} = (\mathbb{1} - \eta)\, U \qquad \eta = \frac{v^2}{4 f \Lambda^2} U\, \widehat{m}_\nu^{1/2}\, \mathcal{H}^T\, \mathcal{H}^*\, \widehat{m}_\nu^{1/2}\, U^\dagger$$



Dynamical ISS in MFV – Case B

$\mathcal{G}_F^{\mathrm{NA}} = SU(3)_V \times SU(3)_{e_R}$ $\quad N_R, S_R \sim (\mathbf{3}, 1)$

Dynamical ISS in MFV – Case B

$$\mathcal{G}_F^{\rm NA} = SU(3)_V \times SU(3)_{e_R} \qquad N_R, S_R \sim (\mathbf{3}, 1)$$

$$\begin{aligned}-\mathscr{L}_Y^{\rm B} = &\ \overline{\ell_L} H Y_e e_R \left(\frac{\Phi}{\Lambda_\Phi}\right)^{x_e - x_\ell} + c_{\nu N}\overline{\ell_L}\widetilde{H} N_R + c_{\nu S}\overline{\ell_L}\widetilde{H} S_R \left(\frac{\Phi}{\Lambda_\Phi}\right)^{2x_\ell} + \\ &+ \frac{1}{2} c_N \overline{N_R^c} Y_N N_R \Phi \left(\frac{\Phi}{\Lambda_\Phi}\right)^{2x_\ell - 1} + \frac{1}{2}\overline{S_R^c} Y_N S_R \Phi^\dagger \left(\frac{\Phi^\dagger}{\Lambda_\Phi}\right)^{2x_\ell - 1} + \\ &+ \Lambda\, \overline{N_R^c} Y_N S_R + \text{h.c.}\,,\end{aligned}$$

$$\mathcal{M}_\chi = \begin{pmatrix} 0 & c_{\nu N}\frac{v}{\sqrt{2}} & c_{\nu S}\frac{v}{\sqrt{2}}\varepsilon^{2x_\ell} \\ c_{\nu N}\frac{v}{\sqrt{2}} & c_N \frac{v_\Phi}{\sqrt{2}}\varepsilon^{2x_\ell - 1} Y_N & \Lambda Y_N \\ c_{\nu S}\frac{v}{\sqrt{2}}\varepsilon^{2x_\ell} & \Lambda Y_N & \frac{v_\Phi}{\sqrt{2}}\varepsilon^{2x_\ell - 1} Y_N \end{pmatrix}$$

Dynamical ISS in MFV – Case B

$$\mathcal{G}_F^{\rm NA} = SU(3)_V \times SU(3)_{e_R}$$

$N_R, S_R \sim (\mathbf{3}, 1)$

$$-\mathscr{L}_Y^{\rm B} = \overline{\ell_L} H Y_e e_R \left(\frac{\Phi}{\Lambda_\Phi}\right)^{x_e - x_\ell} + c_{\nu N} \overline{\ell_L} \widetilde{H} N_R + c_{\nu S} \overline{\ell_L} \widetilde{H} S_R \left(\frac{\Phi}{\Lambda_\Phi}\right)^{2x_\ell} + \frac{1}{2} c_N \overline{N_R^c} Y_N N_R \Phi \left(\frac{\Phi}{\Lambda_\Phi}\right)^{2x_\ell - 1} + \frac{1}{2} \overline{S_R^c} Y_N S_R \Phi^\dagger \left(\frac{\Phi^\dagger}{\Lambda_\Phi}\right)^{2x_\ell - 1} + \Lambda \, \overline{N_R^c} Y_N S_R + \text{h.c.}\,,$$

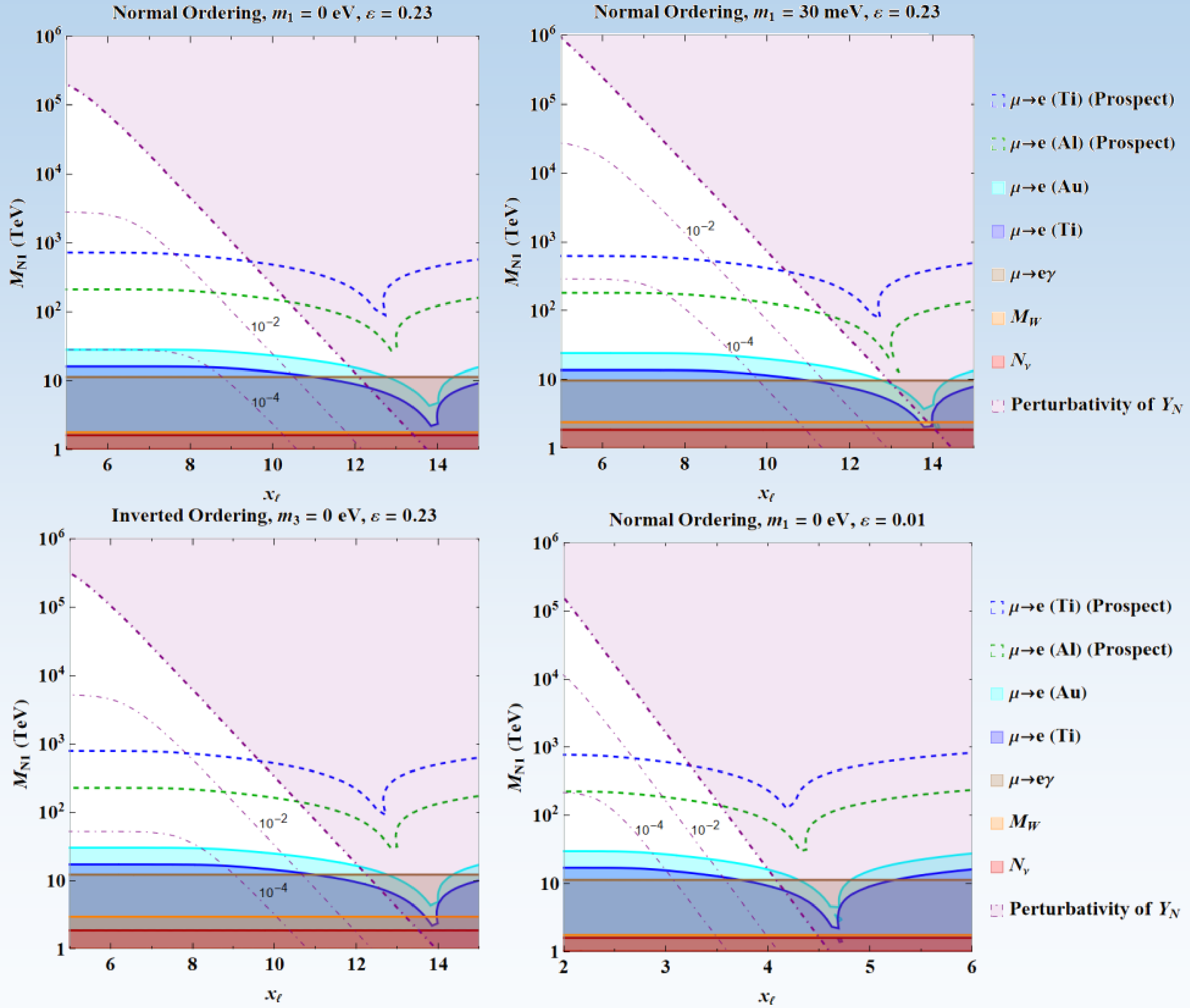
$$\mathcal{M}_\chi = \begin{pmatrix} 0 & c_{\nu N} \frac{v}{\sqrt{2}} & c_{\nu S} \frac{v}{\sqrt{2}} \varepsilon^{2x_\ell} \\ c_{\nu N} \frac{v}{\sqrt{2}} & c_N \frac{v_\Phi}{\sqrt{2}} \varepsilon^{2x_\ell - 1} Y_N & \Lambda Y_N \\ c_{\nu S} \frac{v}{\sqrt{2}} \varepsilon^{2x_\ell} & \Lambda Y_N & \frac{v_\Phi}{\sqrt{2}} \varepsilon^{2x_\ell - 1} Y_N \end{pmatrix}$$

$$Y_N = f\, U^* \widehat{m}_\nu^{-1} U^\dagger\,, \qquad f \equiv \frac{v^2}{2} \varepsilon^{2x_\ell - 1} \left(\frac{c_{\nu_N}^2 v_\Phi}{\sqrt{2}\Lambda^2} - \frac{2 c_{\nu_N} c_{\nu_S} \varepsilon}{\Lambda} \right) \qquad M_N \simeq \Lambda Y_N$$

Dynamical ISS in MFV – Case B

$$\mathcal{N} = (\mathbb{1} - \eta)\, U$$

$$\eta = \frac{c_{\nu N}^2 v^2}{4 f^2 \Lambda^2} U\, \widehat{m}_\nu^2\, U^\dagger$$

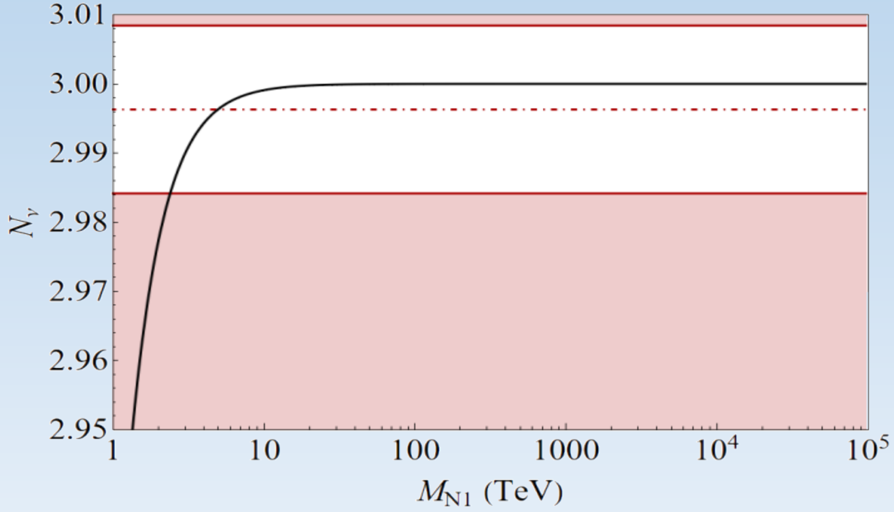


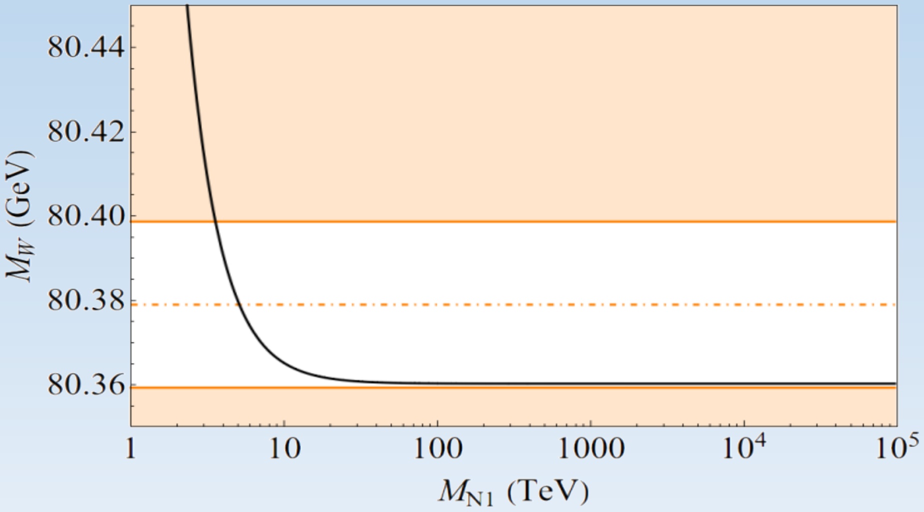
Dynamical ISS in MFV – Case C

$$\mathcal{N} = (\mathbb{1} - \eta)\, U \qquad \eta = \frac{c_{\nu N}^2 v^2}{4\Lambda^2}\, \mathbb{1}$$

Dynamical ISS in MFV – Case C

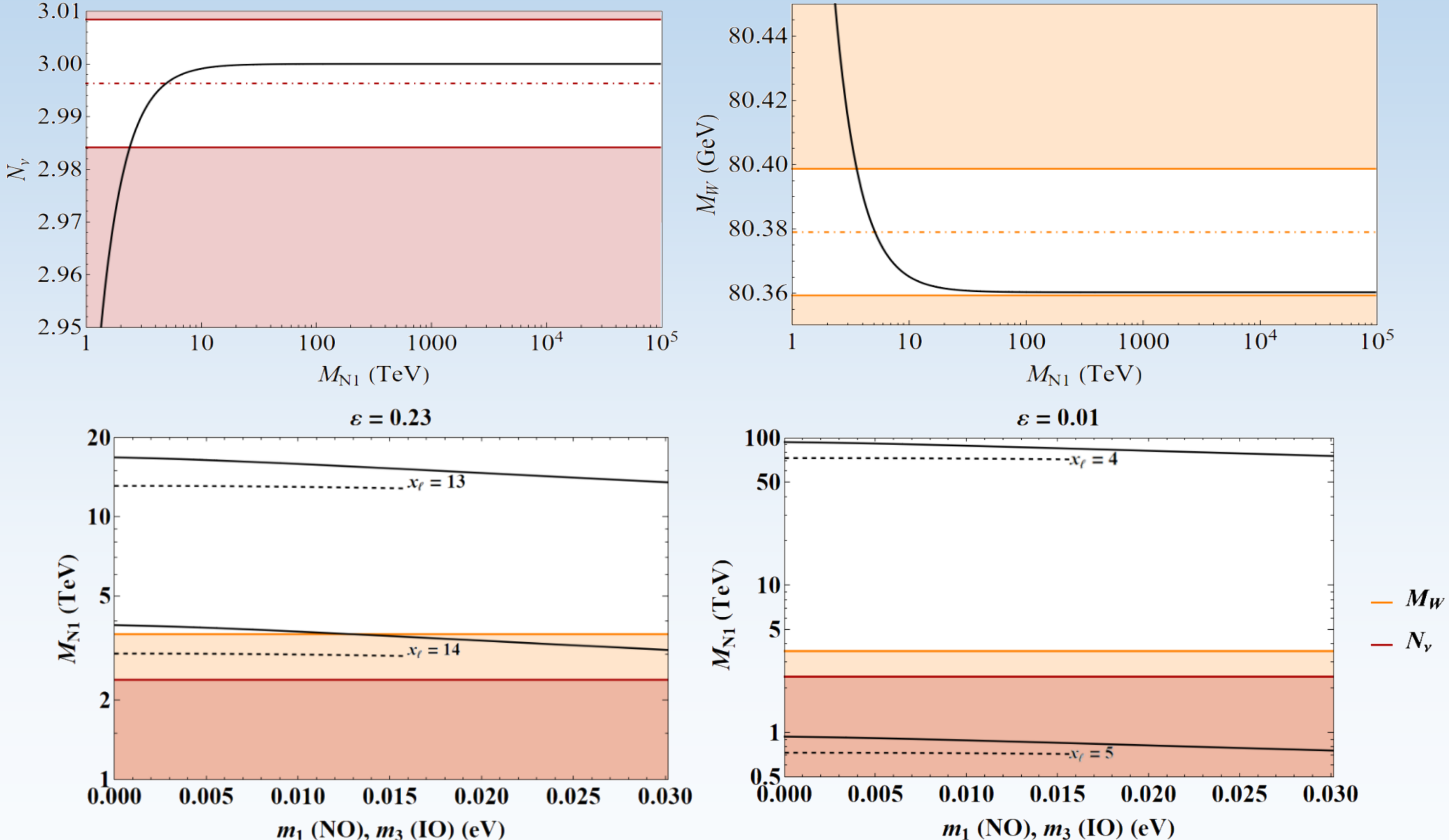
$$\mathcal{N} = (\mathbb{1} - \eta)\, U \qquad \eta = \frac{c_{\nu N}^2 v^2}{4\Lambda^2}\, \mathbb{1}$$





Dynamical ISS in MFV – Case C

$$\mathcal{N} = (\mathbb{1} - \eta)\, U \qquad \eta = \frac{c_{\nu N}^2 v^2}{4\Lambda^2}\, \mathbb{1}$$



Overview

Overview

- Inverse Seesaw embedded dynamically within MLFV

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- Inverse Seesaw embedded dynamically within MLFV
- Strong CP Problem and Dark Matter addressed by the resulting axion

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Case A			
Case B			
Case C			

Overview

- Inverse Seesaw embedded dynamically within MLFV
- Strong CP Problem and Dark Matter addressed by the resulting axion

	LFV	M_{N1} (TeV)	Best Probes
Case A			
Case B			
Case C			

Overview

- Inverse Seesaw embedded dynamically within MLFV
- Strong CP Problem and Dark Matter addressed by the resulting axion

	LFV	M_{N1} (TeV)	Best Probes
Case A	✔	$\gtrsim \mathcal{O}(1)$	Colliders Indirect
Case B			
Case C			

Overview

- Inverse Seesaw embedded dynamically within MLFV
- Strong CP Problem and Dark Matter addressed by the resulting axion

	LFV	M_{N1} (TeV)	Best Probes
Case A	✔	$\gtrsim \mathcal{O}(1)$	Colliders Indirect
Case B	✔	$\gtrsim \mathcal{O}(10)$	Indirect
Case C			

Overview

- Inverse Seesaw embedded dynamically within MLFV
- Strong CP Problem and Dark Matter addressed by the resulting axion

	LFV	M_{N1} (TeV)	Best Probes
Case A	✔	$\gtrsim \mathcal{O}(1)$	Colliders Indirect
Case B	✔	$\gtrsim \mathcal{O}(10)$	Indirect
Case C	✘	$\gtrsim \mathcal{O}(1)$ [2.4,2.9](CDF)	Colliders

Thank you for your attention

Backup slides

Dynamical ISS in MFV – Case C

$$\mathcal{G}_F^{\rm NA} = SU(3)_V \times SU(3)_{e_R}$$

$N_R \sim (\mathbf{3}, 1), \bar{S}_R \sim (\mathbf{3}, 1)$

$$-\mathscr{L}_Y^{\rm C} = \overline{\ell_L} H Y_e e_R \left(\frac{\Phi}{\Lambda_\Phi}\right)^{x_e - x_\ell} + c_{\nu N} \overline{\ell_L} \widetilde{H} N_R + c_{\nu S} \overline{\ell_L} \widetilde{H}\, Y_N^\dagger S_R \left(\frac{\Phi}{\Lambda_\Phi}\right)^{2x_\ell} + \\ + \frac{1}{2} c_N \overline{N_R^c} Y_N N_R \Phi \left(\frac{\Phi}{\Lambda_\Phi}\right)^{2x_\ell - 1} + \frac{1}{2} \overline{S_R^c} Y_N^\dagger S_R \Phi^\dagger \left(\frac{\Phi^\dagger}{\Lambda_\Phi}\right)^{2x_\ell - 1} + \\ + \Lambda\, \overline{N_R^c} S_R + \text{h.c.}\,,$$

$$\mathcal{M}_\chi = \begin{pmatrix} 0 & c_{\nu N} \frac{v}{\sqrt{2}} & c_{\nu S} \frac{v}{\sqrt{2}} \varepsilon^{2x_\ell}\, Y_N^\dagger \\ c_{\nu N} \frac{v}{\sqrt{2}} & c_N \frac{v_\Phi}{\sqrt{2}} \varepsilon^{2x_\ell - 1}\, Y_N & \Lambda \\ c_{\nu S} \frac{v}{\sqrt{2}} \varepsilon^{2x_\ell}\, Y_N^\dagger & \Lambda & \frac{v_\Phi}{\sqrt{2}} \varepsilon^{2x_\ell - 1}\, Y_N^\dagger \end{pmatrix}$$

$$Y_N = \frac{1}{f} U^* \widehat{m}_\nu\, U^\dagger \qquad f \equiv \frac{v^2}{2} \varepsilon^{2x_\ell - 1} \left(\frac{c_{\nu_N}^2 v_\Phi}{\sqrt{2}\Lambda^2} - \frac{2 c_{\nu_N} c_{\nu_S} \varepsilon}{\Lambda} \right) \qquad M_N \simeq \Lambda$$

Dynamical ISS in MFV – Setup

$$M_W = M_Z \sqrt{\frac{1}{2} + \sqrt{\frac{1}{4} - \frac{\pi \alpha_{\text{em}}(1-\eta_{\mu\mu}-\eta_{ee})}{\sqrt{2} G_\mu M_Z^2}}}$$

$$\Gamma_{\text{Z-inv}} = \frac{G_\mu M_Z^3}{12\sqrt{2}\pi}(3 - 4\eta_{\tau\tau} - \eta_{ee} - \eta_{\mu\mu})$$

$$\text{BR}(\ell_i \to \ell_j \gamma) \equiv \frac{\Gamma(\ell_i \to \ell_j \gamma)}{\Gamma(\ell_i \to \ell_j \nu \overline{\nu})} = \frac{3\alpha_{\text{em}}}{2\pi} |\eta_{\ell_j \ell_i}|^2$$

$$R_{\mu\to e} = \frac{\sigma(\mu^- X \to e^- X)}{\sigma(\mu^- X \to \text{Capture})} \simeq \frac{G_\mu^2 \alpha_{\text{em}}^5 m_\mu^5}{2 s_w^4 \pi^4 \Gamma_{\text{capt}}} \frac{Z_{\text{eff}}^4}{Z} |\eta_{e\mu}|^2 F_p^2 \Big[(A+Z)\, F_u + (2A - Z)\, F_d \Big]^2$$

$$F_u = \frac{2}{3} s_W^2 \frac{16 \log\left(\frac{M_N^2}{M_W^2}\right) - 31}{12} - \frac{3 + 3\log\left(\frac{M_N^2}{M_W^2}\right)}{8}$$

$$F_d = -\frac{1}{3} s_W^2 \frac{16 \log\left(\frac{M_N^2}{M_W^2}\right) - 31}{12} - \frac{3 - 3\log\left(\frac{M_N^2}{M_W^2}\right)}{8}$$

Nucleus ${}^A_Z N$	Z_{eff}	F_p	$\Gamma_{\text{capt}} (10^6\,\text{s}^{-1})$
${}^{27}_{13}$ Al	11.5	0.64	0.7054
${}^{48}_{22}$ Ti	17.6	0.54	2.59
${}^{197}_{79}$ Au	33.5	0.16	13.07

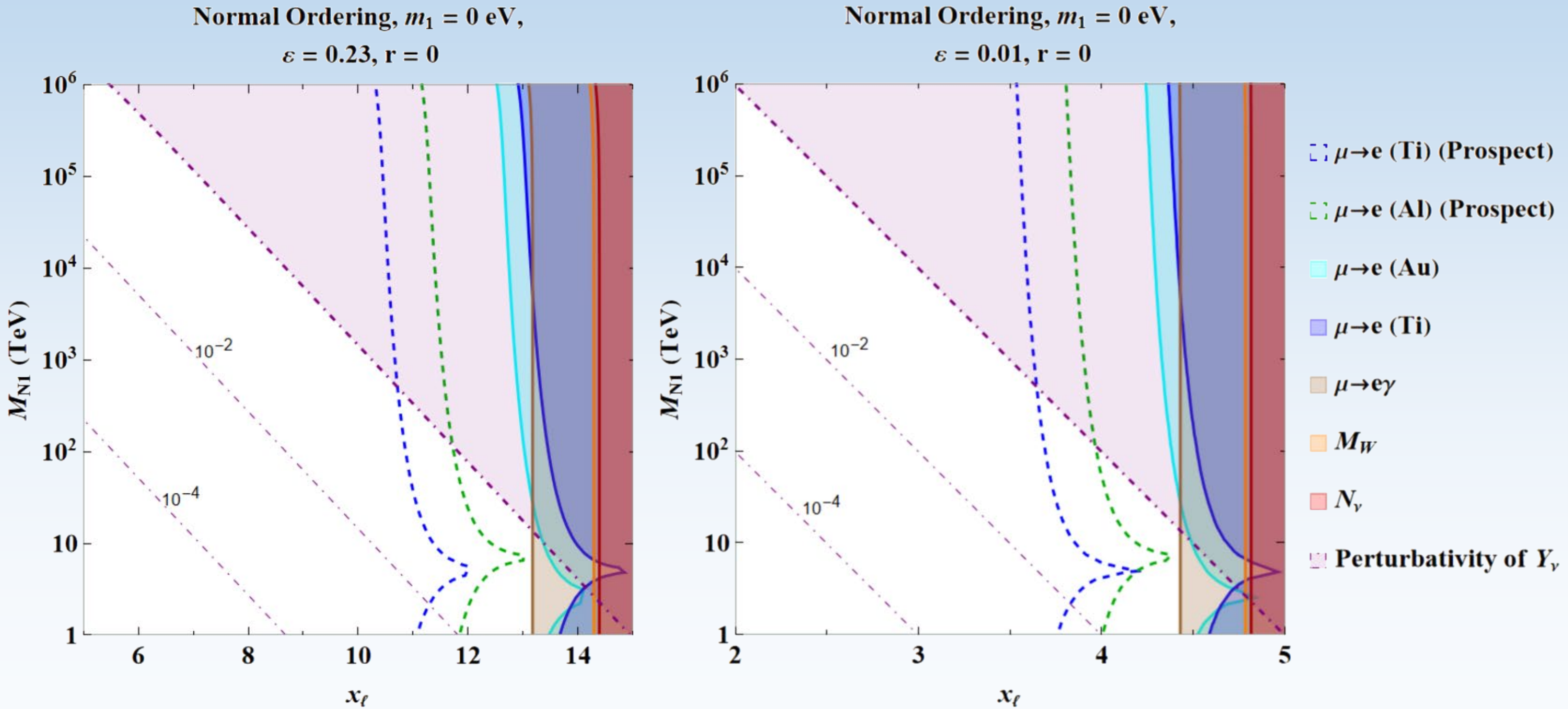
Dynamical ISS in MFV – Setup

Observable	Normal Ordering	Inverted Ordering
$\sin^2\theta_{12}$	$0.304^{+0.012}_{-0.012}$	$0.304^{+0.013}_{-0.012}$
$\sin^2\theta_{23}$	$0.450^{+0.019}_{-0.016}$	$0.570^{+0.016}_{-0.022}$
$\sin^2\theta_{13}$	$0.02246^{+0.00062}_{-0.00062}$	$0.02241^{+0.00074}_{-0.00062}$
$\delta_{CP}/^\circ$	-130^{+36}_{-25}	-82^{+22}_{-30}
$\frac{\Delta m^2_{sol}}{10^{-5}\ eV^2}$	$7.42^{+0.21}_{-0.20}$	$7.42^{+0.21}_{-0.20}$
$\frac{\lvert\Delta m^2_{atm}\rvert}{10^{-3}\ eV^2}$	$2.510^{+0.027}_{-0.027}$	$2.490^{+0.026}_{-0.028}$

Observable	Experimental Bound	Future Sensitivity
$BR(\mu \to e\gamma)$	4.2×10^{-13}	6×10^{-14}
$BR(\tau \to e\gamma)$	1.9×10^{-7}	9×10^{-9}
$BR(\tau \to \mu\gamma)$	2.5×10^{-7}	6.9×10^{-9}
$R_{\mu\to e}(Al)$	–	6×10^{-17}
$R_{\mu\to e}(Ti)$	4.3×10^{-12}	10^{-18}
$R_{\mu\to e}(Au)$	7×10^{-13}	–

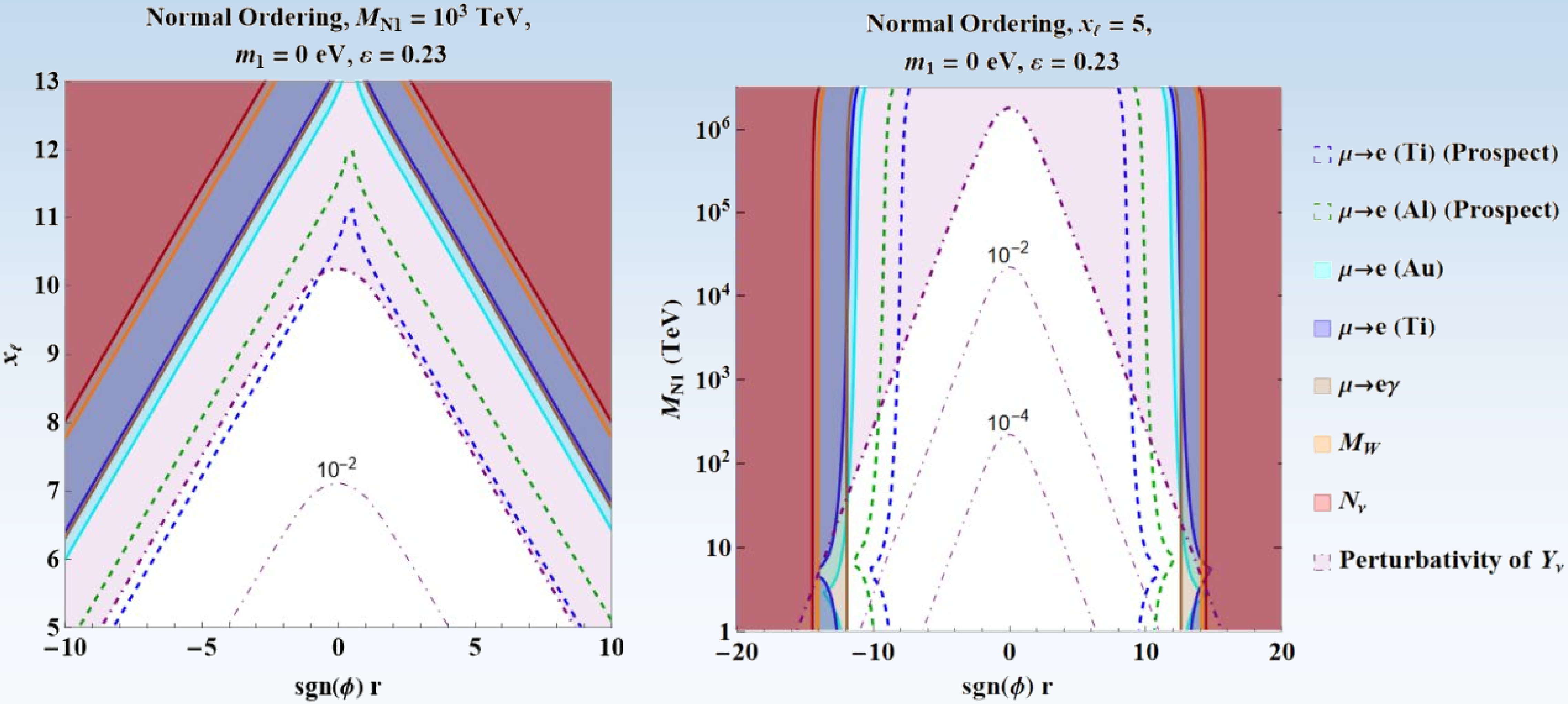
Dynamical ISS in MFV – Case A

$$\mathcal{N} = (\mathbb{1} - \eta)\, U \qquad \eta = \frac{v^2}{4 f \Lambda^2} U\, \widehat{m}_\nu^{1/2}\, \mathcal{H}^T\, \mathcal{H}^*\, \widehat{m}_\nu^{1/2}\, U^\dagger$$



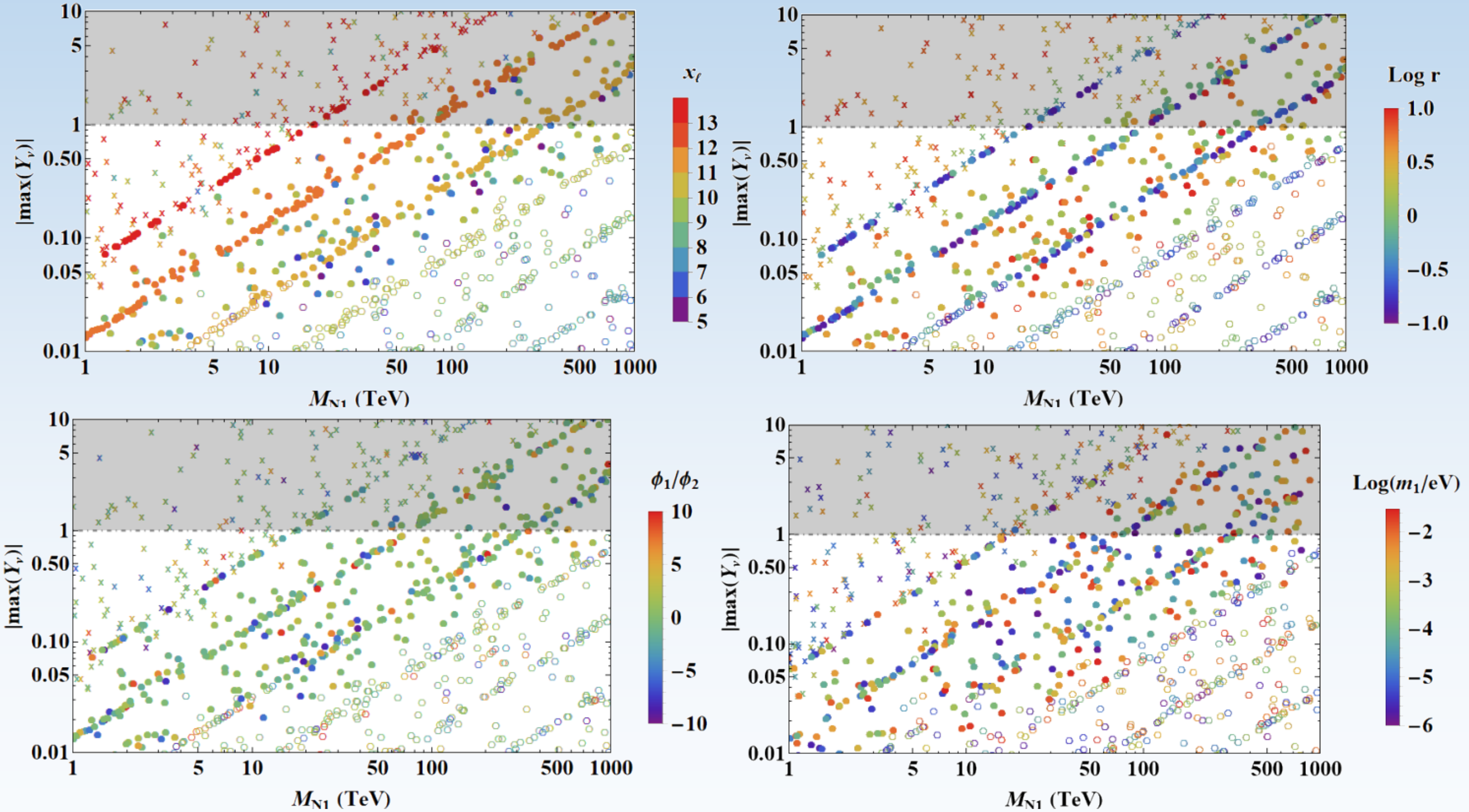
Dynamical ISS in MFV – Case A

$$\mathcal{N} = (\mathbb{1} - \eta)\, U \qquad \eta = \frac{v^2}{4 f \Lambda^2} U\, \widehat{m}_\nu^{1/2}\, \mathcal{H}^T\, \mathcal{H}^*\, \widehat{m}_\nu^{1/2}\, U^\dagger$$



Dynamical ISS in MFV – Case A

$$\mathcal{N} = (\mathbb{1} - \eta)\, U \qquad \eta = \frac{v^2}{4 f \Lambda^2} U\, \widehat{m}_\nu^{1/2}\, \mathcal{H}^T\, \mathcal{H}^*\, \widehat{m}_\nu^{1/2}\, U^\dagger$$

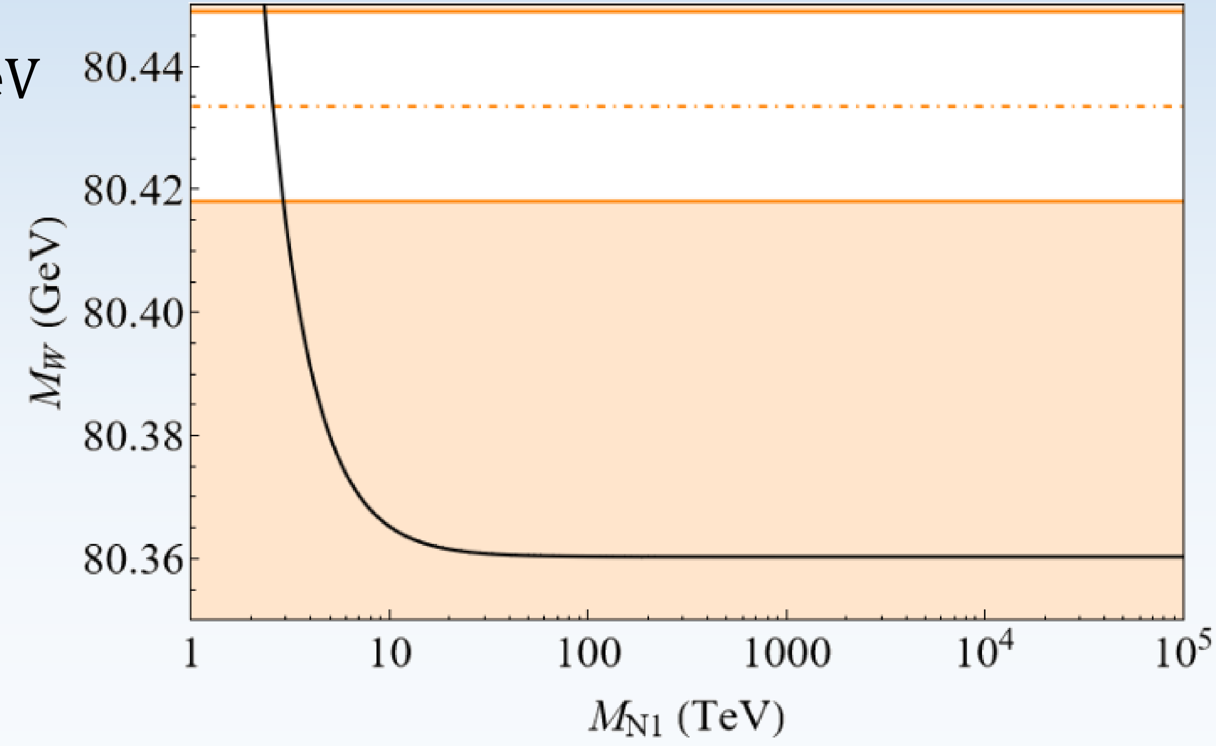


Impact of the CDF Measurement of M_W

- New very precise measurement of $M_W = 80{,}4335(94)$ GeV

CDF Collaboration, Science 376 (2022), no. 6589 170-176

- Cases A and B not compatible with the new value
- Case C is not constrained by LFV processes
- Sharp prediction for $M_{N1} \in [2.4, 2.9]$ TeV



The MFVA – Setup

- The axion arises as the angular part of Φ

$$\Phi = \frac{\rho + v_\Phi}{\sqrt{2}} e^{ia/v_\Phi}$$

- After integrating out ρ, the axion couplings read

$$- e^{i(x_u - x_q)a/v_\Phi} \bar{q}_L \widetilde{H} Y_u u_R - e^{i(x_d - x_q)a/v_\Phi} \bar{q}_L H Y_d d_R - e^{i(x_e - x_l)a/v_\Phi} \bar{l}_L H Y_e e_R$$

$$\downarrow$$

$$c_{a\psi} \frac{\partial_\mu a}{2 v_\Phi} \bar{\psi} \gamma^\mu \gamma_5 \psi$$

$$c_{au} = x_q - x_u$$

$$c_{ad} = x_q - x_d$$

$$c_{ae} = x_l - x_e$$

$$c_{agg} = 3(c_{au} + c_{ad}), \quad c_{aWW} = \frac{3}{2 s_\theta^2} \left(3\left(c_{au} + c_{ad}\right) + c_{ae}\right),$$

$$c_{aZZ} = \frac{t_\theta^2}{4} \left(17 c_{au} + 5 c_{ad} + 15 c_{ae}\right) + \frac{3}{4 t_\theta^2} \left(3(c_{au} + c_{ad}) + c_{ae}\right),$$

$$c_{a\gamma Z} = \frac{t_\theta}{4} \left(17 c_{au} + 5 c_{ad} + 15 c_{ae}\right) - \frac{3}{4 t_\theta} \left(3(c_{au} + c_{ad}) + c_{ae}\right),$$

$$c_{a\gamma\gamma} = 2(4 c_{au} + c_{ad} + 3 c_{ae})$$

$$c_{agg} \neq 0$$

$$\frac{c_{agg}}{c_{a\gamma\gamma}} = 8/3$$

The MFVA – Phenomenology

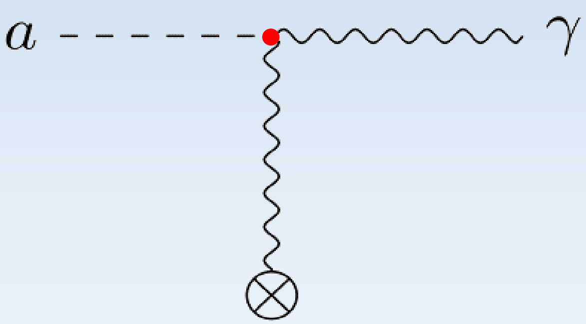
$$f_a = \frac{v_\Phi}{c_{agg}}$$

	x_l	x_e	c_{au}	c_{ad}	c_{ae}	c_{agg}	$c_{a\gamma\gamma}$	c_{aZZ}	$c_{a\gamma Z}$	c_{aWW}
$S0$	0	3	0	-3	-3	-9	-24	-35.8	8.8	-81
$S1$	1	4	0	-3	-3	-9	-24	-35.8	8.8	-81

Jaeckel and Spannowsky, 1509.00476; Bauer et al., 1708.00443

- Astrophysical and cosmological bounds on photon coupling

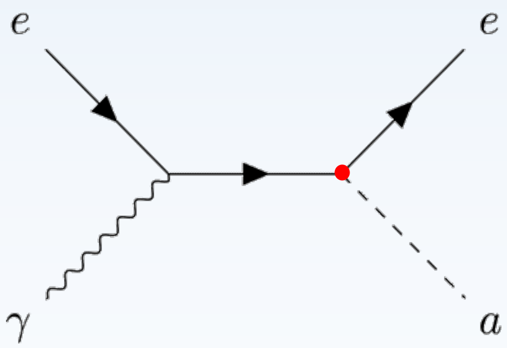
$$f_a \gtrsim 1.2 \times 10^7 \text{ GeV} \quad \text{for} \quad m_a \lesssim 10 \text{ meV},$$
$$f_a \gtrsim 8.7 \times 10^6 \text{ GeV} \quad \text{for} \quad 10 \text{ meV} \lesssim m_a \lesssim 10 \text{ eV},$$
$$f_a \gg 8.7 \times 10^8 \text{ GeV} \quad \text{for} \quad 10 \text{ eV} \lesssim m_a \lesssim 0.1 \text{ GeV},$$
$$f_a \gtrsim 3 \text{ GeV} \quad \text{for} \quad 0.1 \text{ GeV} \lesssim m_a \lesssim 1 \text{ TeV}$$



- Astrophysical bounds on electron coupling

Borexino Collaboration, Bellini et al., 1203.6258; Armengaud et al. 1307.1488; Viaux et al., 1311.1669

$$f_a \gtrsim 3.9 \times 10^8 \text{ GeV} \quad \text{for} \quad m_a \lesssim 1 \text{ eV},$$
$$f_a \gtrsim 6.4 \times 10^6 \text{ GeV} \quad \text{for} \quad 1 \text{ eV} \lesssim m_a \lesssim 10 \text{ MeV}$$



The MFVA – Phenomenology

$$f_a = \frac{v_\Phi}{c_{agg}}$$

	x_l	x_e	c_{au}	c_{ad}	c_{ae}	c_{agg}	$c_{a\gamma\gamma}$	c_{aZZ}	$c_{a\gamma Z}$	c_{aWW}
$S0$	0	3	0	-3	-3	-9	-24	-35.8	8.8	-81
$S1$	1	4	0	-3	-3	-9	-24	-35.8	8.8	-81

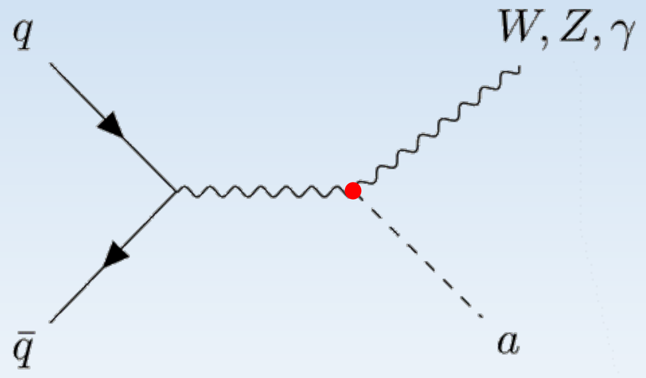
Brivio et al., 1701.05379

- Collider bounds on massive gauge bosons couplings (0,1 GeV $\lesssim m_a \lesssim$ 1 GeV)

(aWW) $\quad f_a \gtrsim 6.4$ GeV

(aZZ) $\quad f_a \gtrsim 5.7$ GeV

$(aZ\gamma)$ $\quad f_a \gtrsim 17.8$ GeV

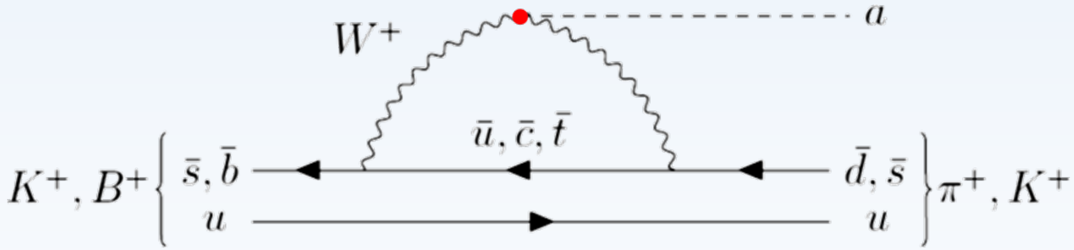


- Flavour bounds on aWW coupling

Izaguirre et al., 1611.09355

$f_a \gtrsim 3.5 \times 10^3$ GeV for $m_a \lesssim 0.2$ GeV

$f_a \gtrsim 105$ GeV for $0.2\ \text{GeV} \lesssim m_a \lesssim 5$ GeV



The MFVA – Phenomenology

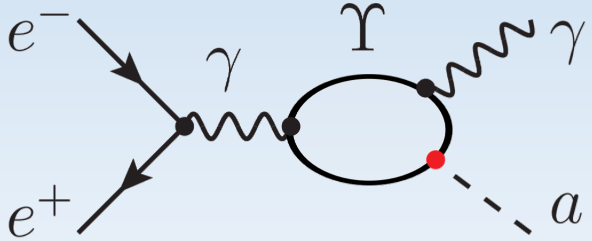
$$f_a = \frac{v_\Phi}{c_{agg}}$$

	x_l	x_e	c_{au}	c_{ad}	c_{ae}	c_{agg}	$c_{a\gamma\gamma}$	c_{aZZ}	$c_{a\gamma Z}$	c_{aWW}
$S0$	0	3	0	-3	-3	-9	-24	-35.8	8.8	-81
$S1$	1	4	0	-3	-3	-9	-24	-35.8	8.8	-81

- Flavour bound on bottom coupling through $\Upsilon \to a\gamma$ ($m_a \sim 1$ GeV)

Merlo et al., 1905.03259

$$f_a \gtrsim 830 \text{ GeV}$$



- Axion-bottom coupling bound from CLEO ($0{,}4 \lesssim m_a \lesssim 4{,}8$ GeV, decaying axion)

CLEO Collaboration, PRL 80 (1998) 1150-1155

$$f_a \gtrsim 667 \text{ GeV}$$