The low-scale seesaw solution to the M_W and $(g-2)_\mu$ anomalies

Based on:

arXiv: **2211.03797**, Fortsch.Phys. 71 (2023)

realised in collaboration with:
L. Merlo (UAM/IFT) and **Stefan Pokorski** (University of Warsaw)

Arturo de Giorgi (Madrid, UAM/IFT)

21st Lomonosov Conference

August 25, 2023

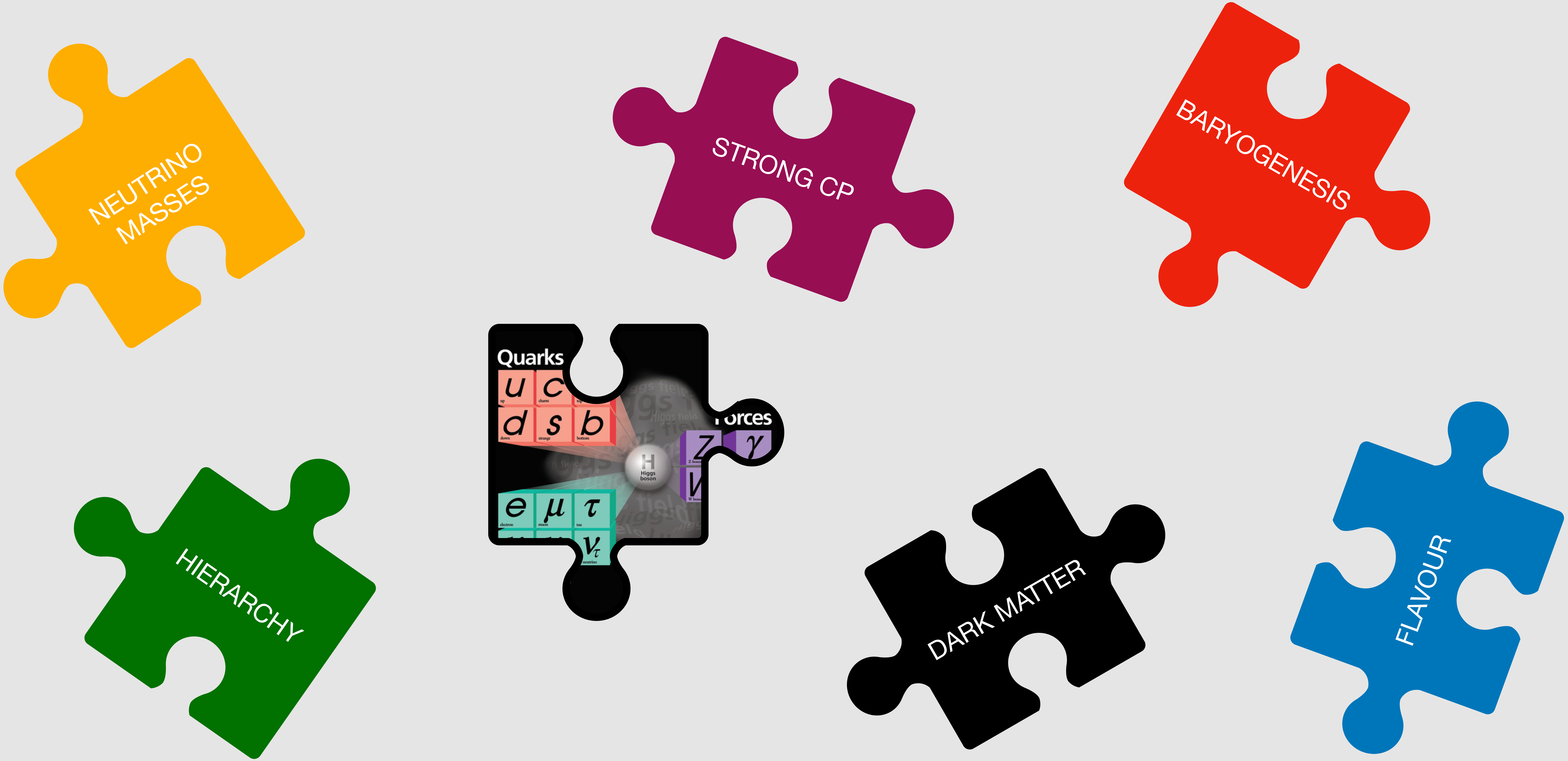
UAM

ift Instituto de Física Teórica UAM-CSIC

HIDDeν Hunting Invisibles: Dark sectors, Dark matter and Neutrinos

This project has received funding /support from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 860881-HIDDeN

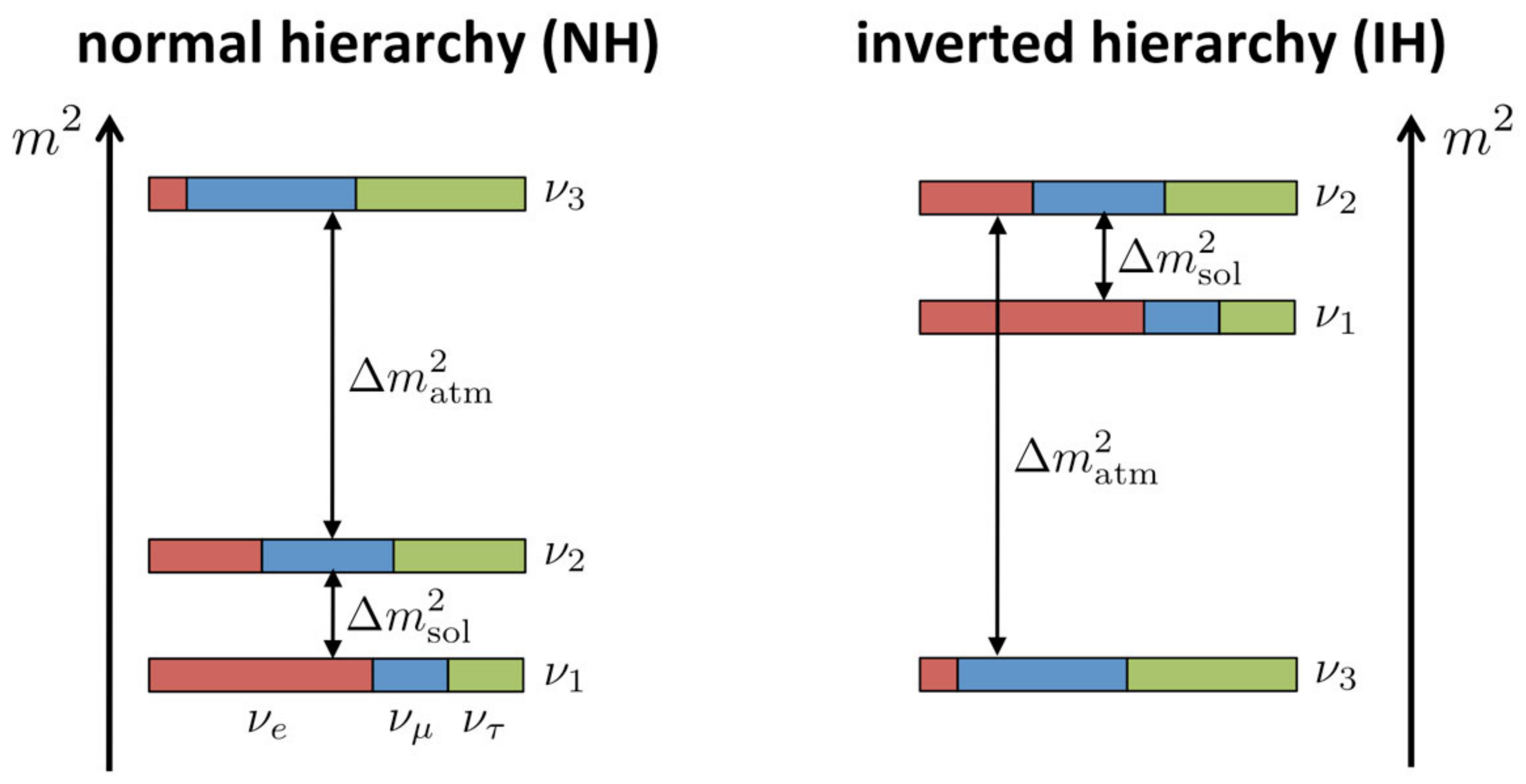
(Some) SM's Problems/Puzzles



ν-Masses

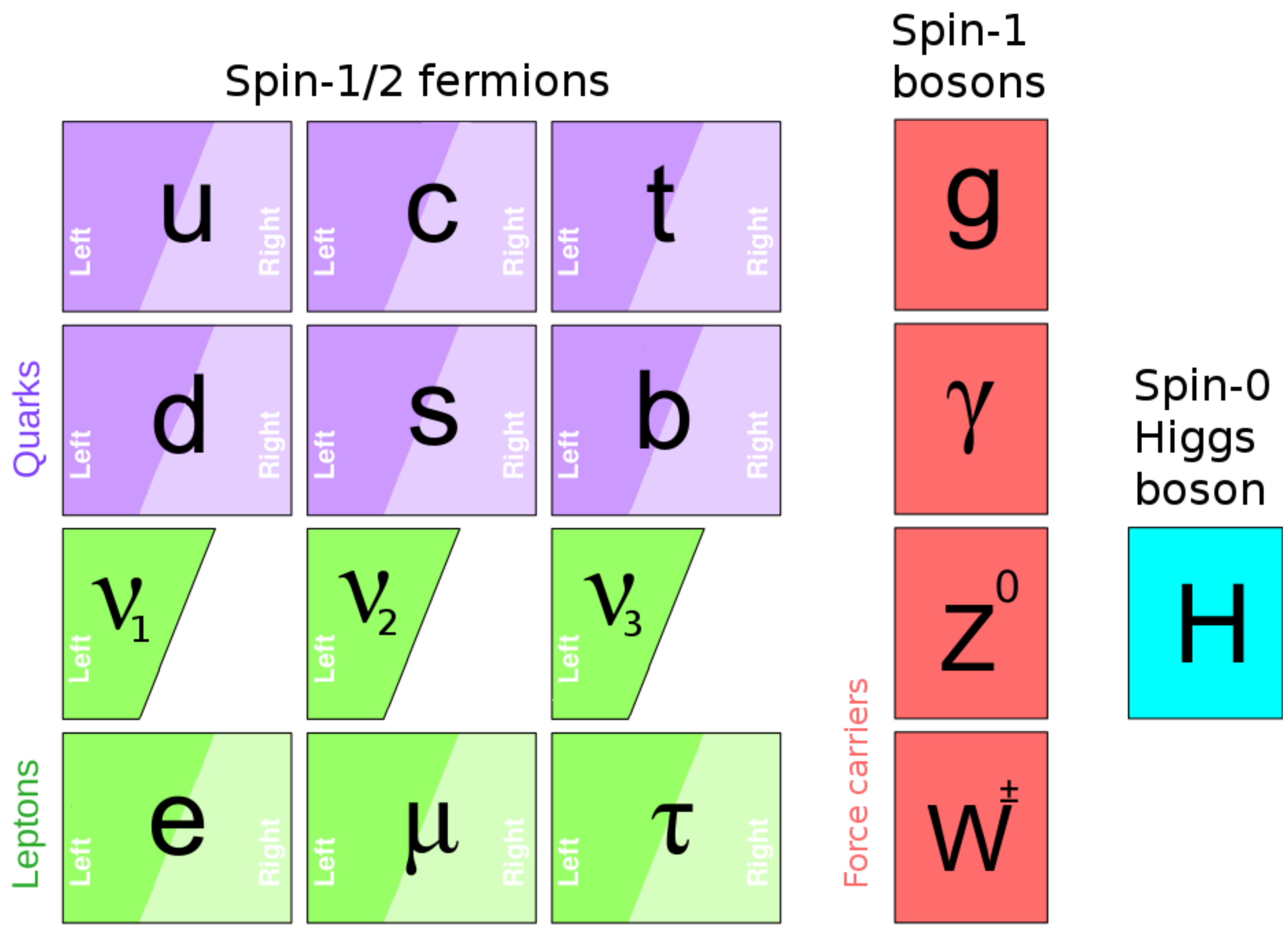
	NO	IO
$\frac{\Delta m^2_{21}}{10^{-5}\ \mathrm{eV}^2}$	$7.41^{+0.21}_{-0.20}$	$7.41^{+0.21}_{-0.20}$
$\frac{\Delta m^2_{3\ell}}{10^{-3}\ \mathrm{eV}^2}$	$+2.507^{+0.026}_{-0.027}$	$-2.486^{+0.025}_{-0.028}$

νFit Collaboration [2007.14792]



Credit: JUNO Collaboration

Sterile Neutrinos?



Credit: arXiv:1704.08635 (NuPhys2016)

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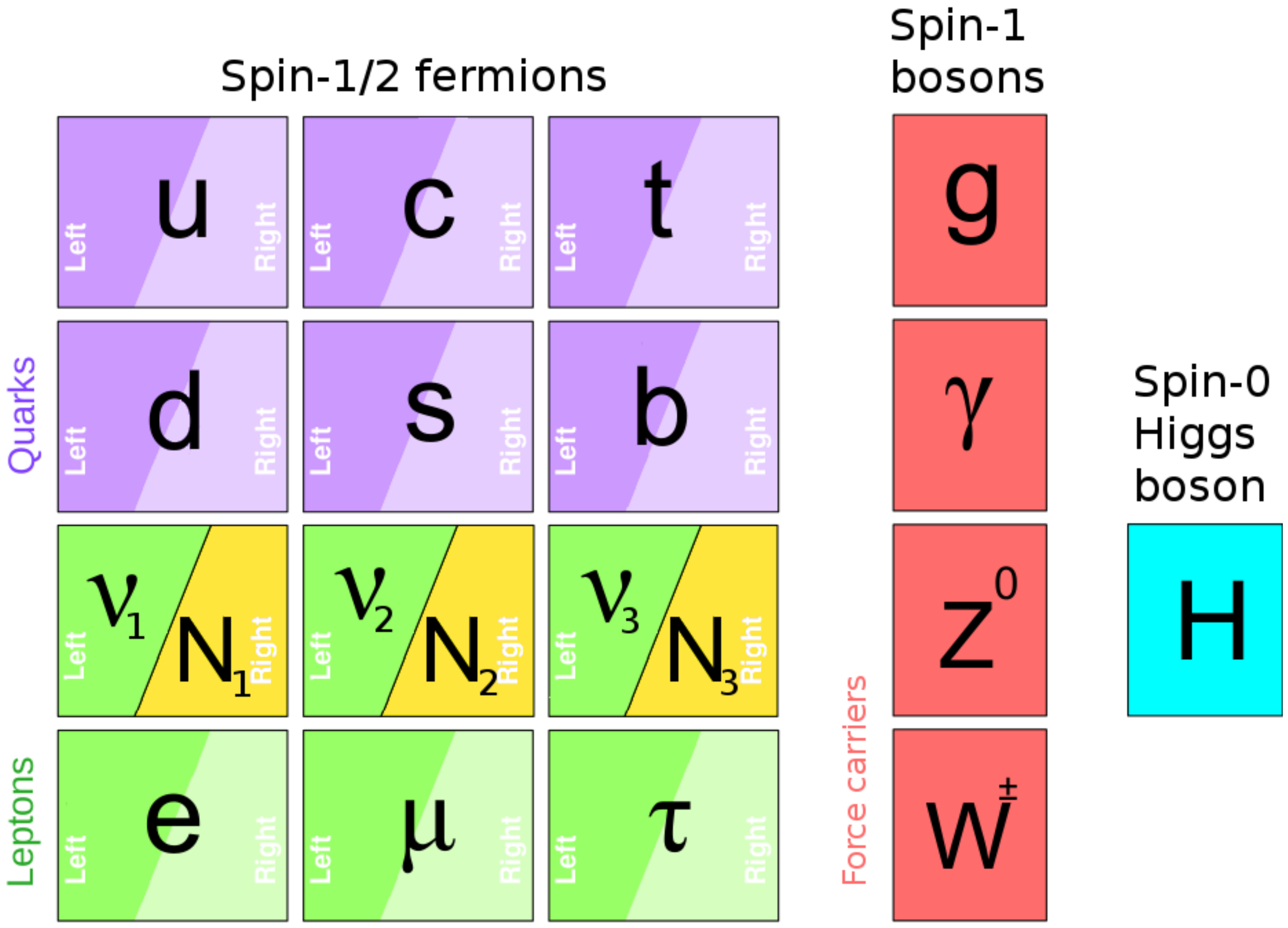

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Seesaw Mechanism?

In the **SMEFT**, only 1-operator at dimension 5 that can describe ν-masses: "**Weinberg-Operator**"

$$\delta\mathcal{L}^{d=5} = \left(\frac{c_{\alpha\beta}}{\Lambda}\right)\left(\overline{\ell^c_{L\alpha}}\tilde{H}^*\right)\left(\tilde{H}^\dagger\,\ell_{L\beta}\right)$$

Steven Weinberg, PRL **43**, 1566 (1979)

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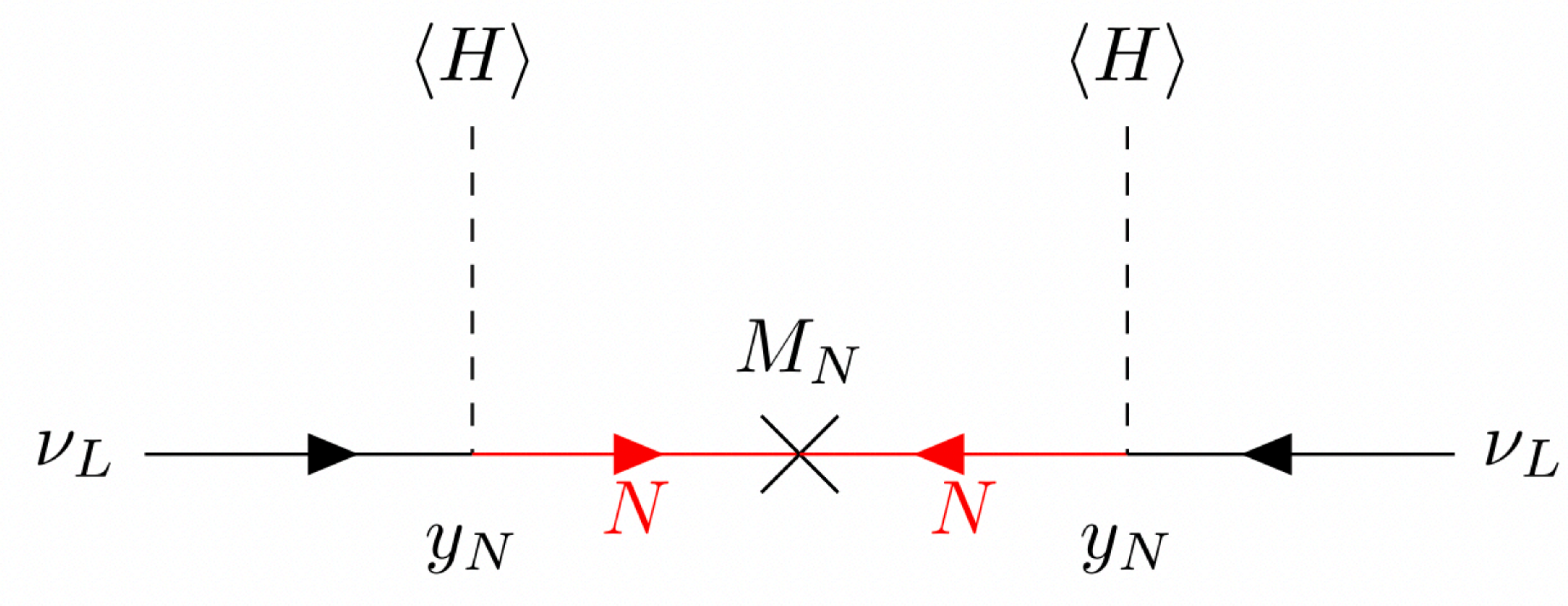
Could we use a very **large scale** to justify the **smallness** of ν-masses?

$$\mathcal{L} \;=\; \mathcal{L}_{SM} + i\bar{N}_\alpha \not{\partial} N_\alpha - \left[\lambda_N^{\alpha b}\bar{N}^\alpha \tilde{H}^\dagger \ell_L^b + \frac{M_{\alpha\beta}}{2}\bar{N}^\alpha N^{\beta c} + h.c.\right]$$

$$M_\nu = \begin{pmatrix} 0 & \lambda_N^T v/\sqrt{2} \\ \lambda_N v/\sqrt{2} & M \end{pmatrix} \qquad m_\nu = \frac{\lambda_N^2 \langle H\rangle^2}{2M_N}$$

$$\lambda_N \sim \mathcal{O}(1) \longrightarrow M_N \sim 10^{14}\ \text{GeV}$$

Diagrammatically:



P. Minkowski, P.L. B 67 (1977).
M. Gell-Mann, P. Ramond, and R. Slansky, Conf. Proc. C 790927 (1979).
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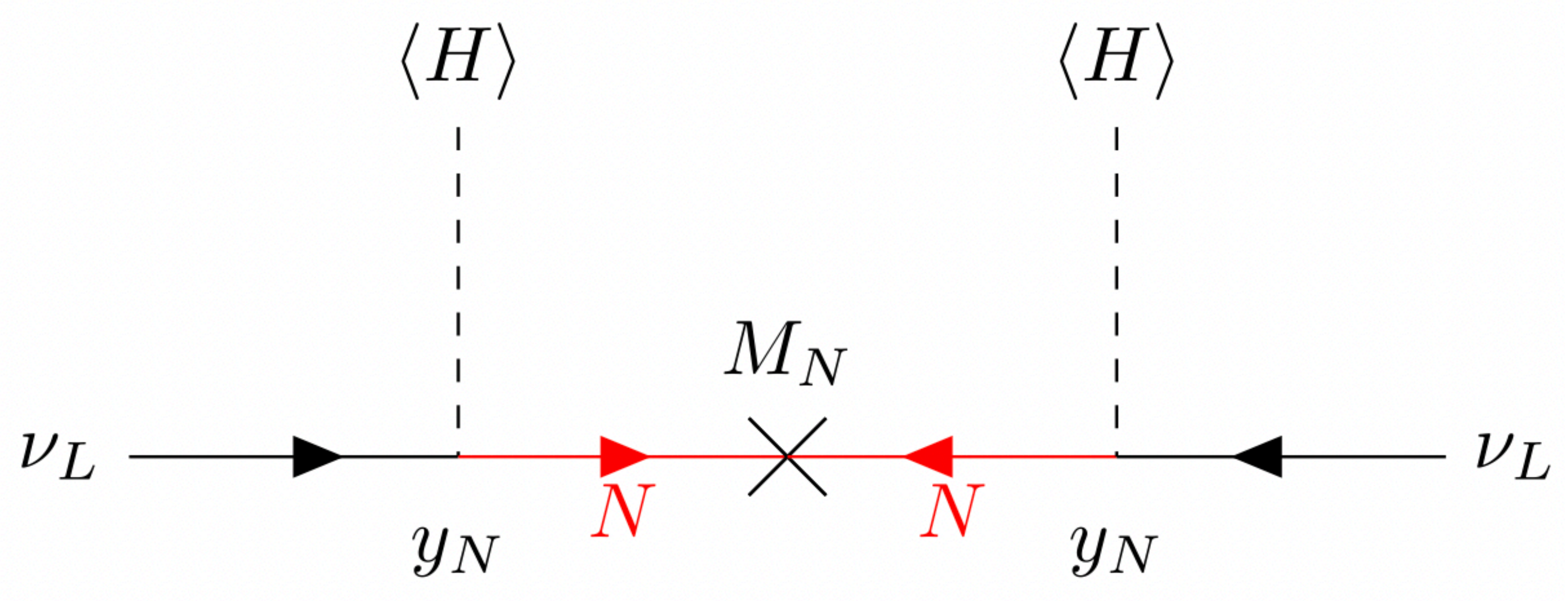

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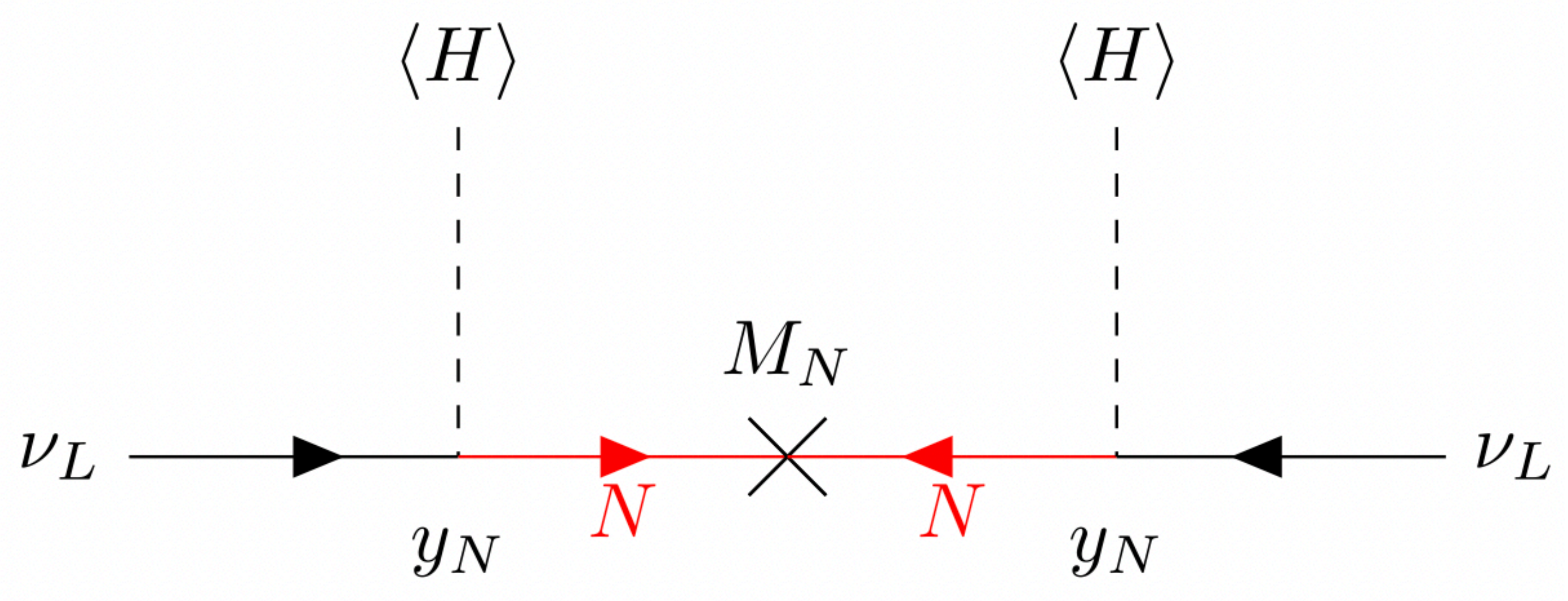
HUGE! Something more "testable"?

Diagrammatically:



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Arturo de Giorgi - **2211.03797**

Low-scale Seesaws: a global symmetry?

Small Symmetry Breaking Parameters

$$-\mathscr{L}_Y = \overline{\ell_L} H Y_\mu \mu_R + \overline{\ell_L}\widetilde{H} Y_N N_R + \epsilon\, \overline{\ell_L}\widetilde{H} Y_S S_R + \frac{1}{2}\mu' \overline{N_R^c} N_R + \frac{1}{2}\mu\, \overline{S_R^c} S_R + \Lambda \overline{N_R^c} S_R$$

$$\chi \equiv (\nu_L,\, N_R^c,\, S_R^c)^T$$

$$-\mathscr{L}_Y \supset \frac{1}{2}\overline{\chi}\mathcal{M}_\chi \chi^c + \text{h.c.}$$

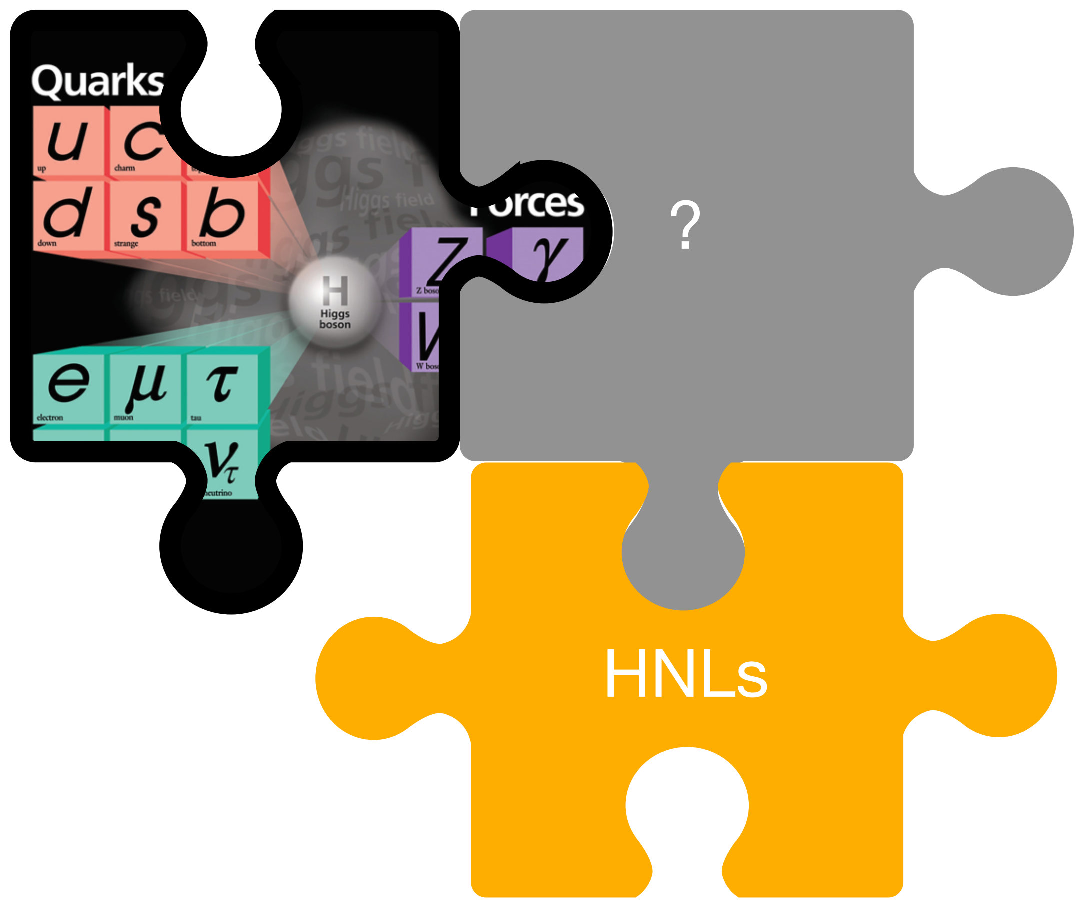
$$\mathcal{M}_\chi = \begin{pmatrix} 0 & \frac{v}{\sqrt{2}}Y_N & \epsilon\frac{v}{\sqrt{2}}Y_S \\ \frac{v}{\sqrt{2}}Y_N^T & \mu' & \Lambda \\ \epsilon\frac{v}{\sqrt{2}}Y_S^T & \Lambda^T & \mu \end{pmatrix}$$

$$m_\nu \simeq \frac{v^2}{2}\left[\left(Y_N \frac{1}{\Lambda^T}\mu\frac{1}{\Lambda}Y_N^T\right) - \epsilon\left(Y_S\frac{1}{\Lambda}Y_N^T + Y_N\frac{1}{\Lambda^T}Y_S^T\right)\right]$$

D. Wyler and L. Wolfenstein, Nucl. Phys. B 218 (1983) 205–214.
R. N. Mohapatra and J. W. F. Valle, Phys. Rev. D 34 (1986) 1642.
J. Bernabeu et al., Phys. Lett. B 187 (1987) 303–308.
M. Malinsky et al., Phys. Rev. Lett. 95 (2005) 161801.

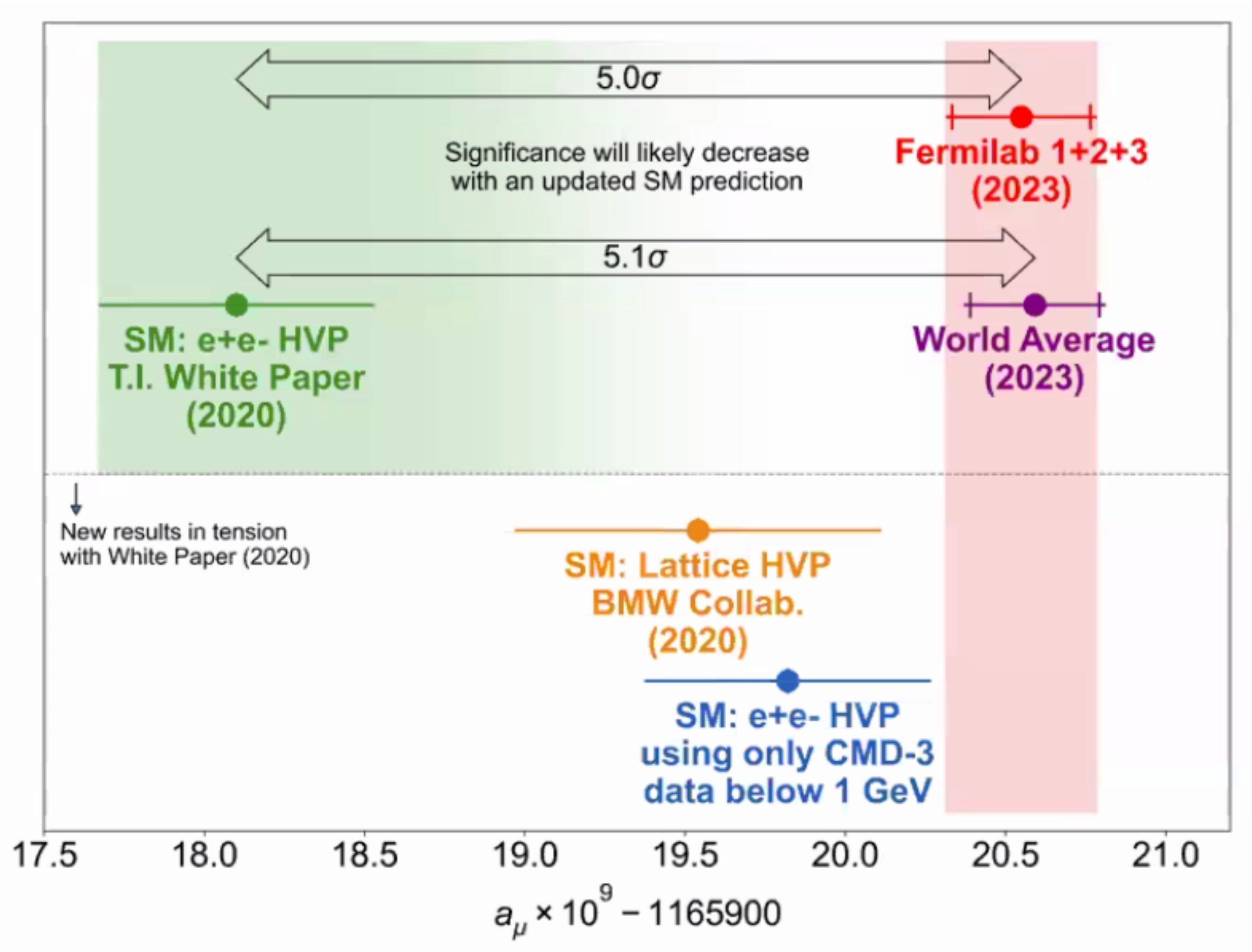
HNLs cannot account for **all problems/puzzles** of the SM

What **extra "piece"** could make a **difference?**



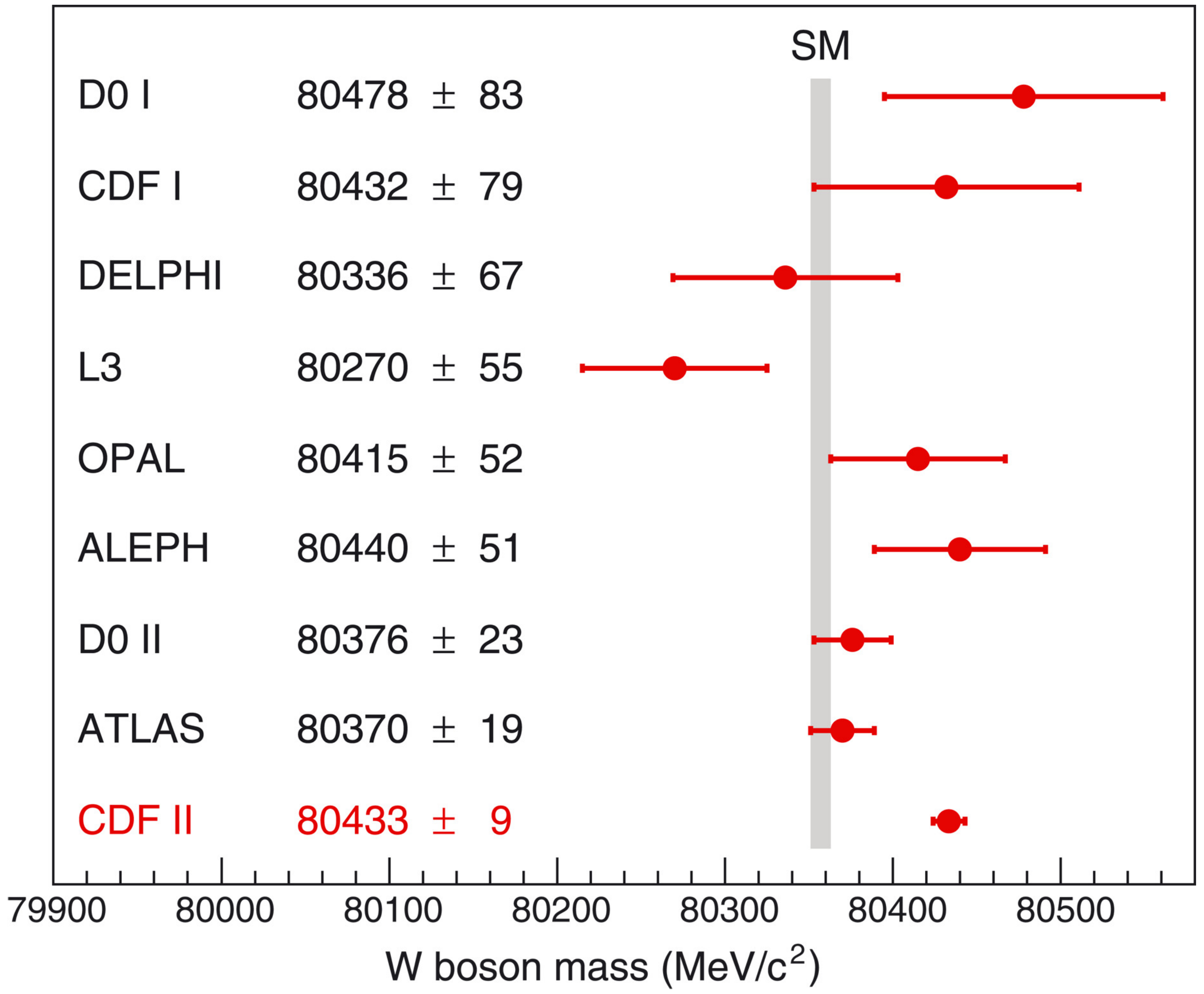
Anomalies?

$(g-2)_\mu$



g-2 Collaboration, arXiv: 2308.06230

M_W



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

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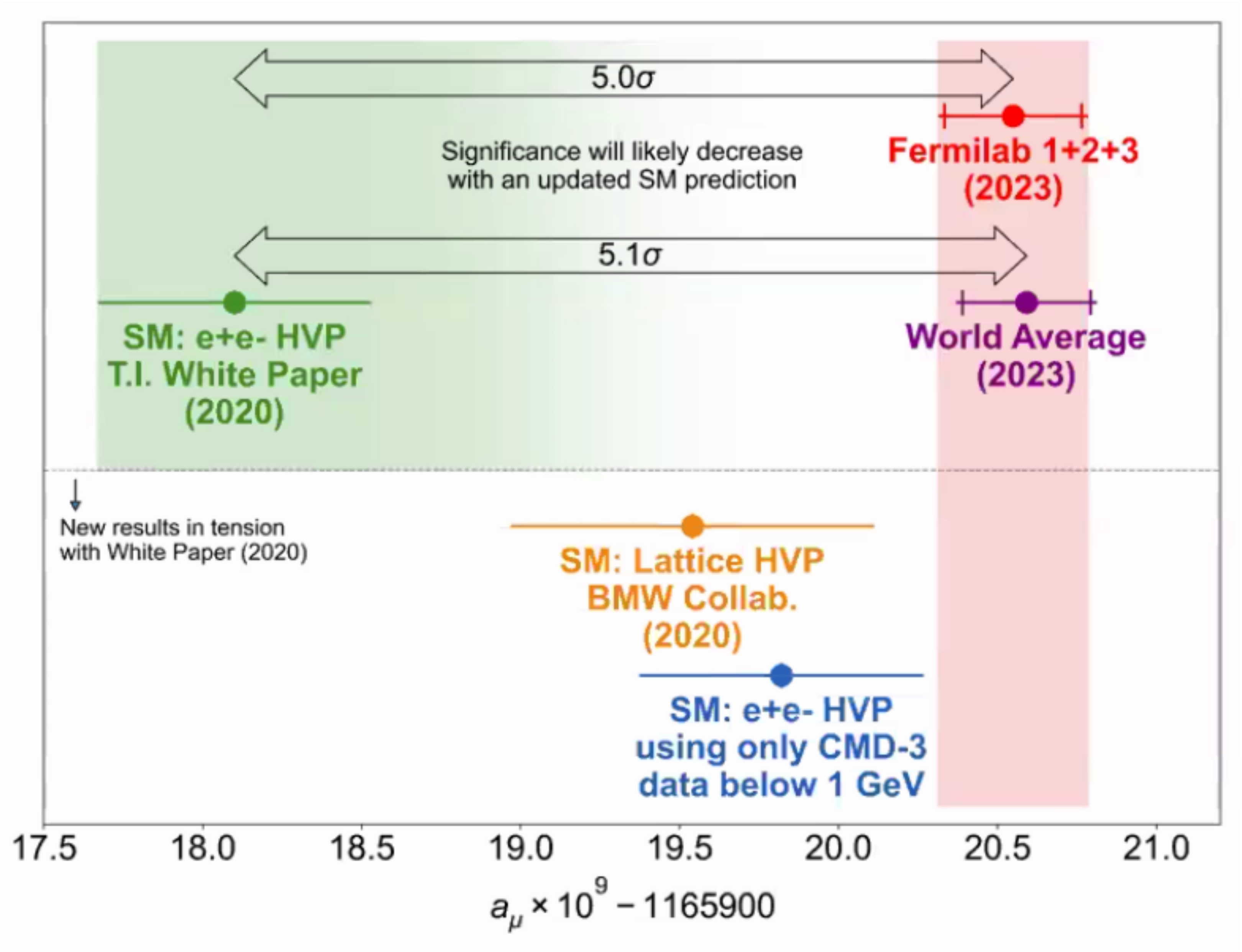
Anomalies?

Внимание! Controversial!

$(g-2)_\mu$



g-2 Collaboration, arXiv: 2308.06230

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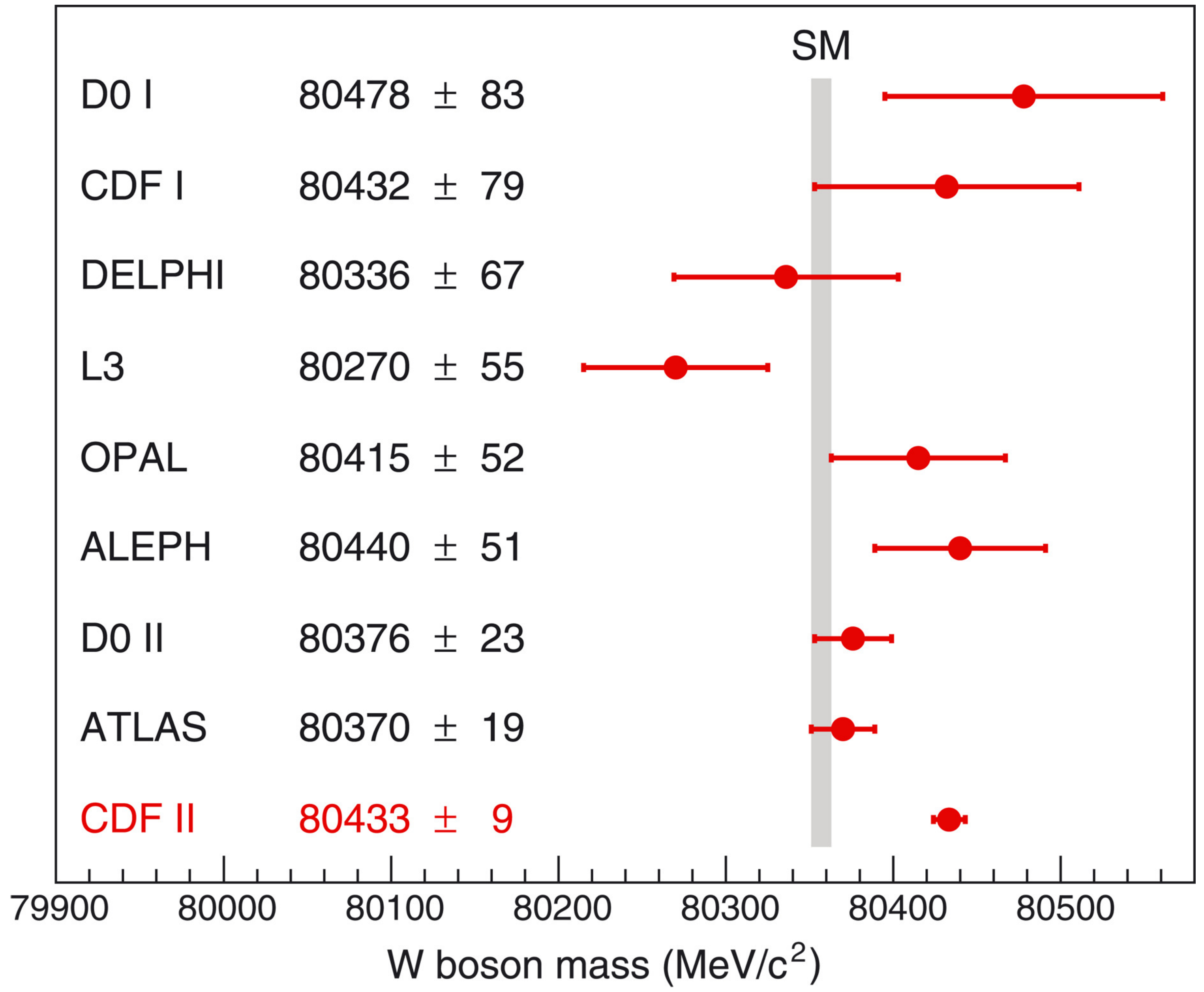

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A Minimal Extension

- **Only** sterile neutrinos?
  - m_ν ? ✅
  - M_W ? ✅
  - $(g-2)_\mu$? ❌

$$\left(\frac{\delta a_\mu}{10^{-9}}\right) \sim \frac{1}{16\pi^2}|\Theta_{\mu N}|^2 G_F m_\mu^2 \sim \mathcal{O}(1)\ |\Theta_{\mu N}|^2$$

K. Kannike et al., JHEP 02 (2012) 106. [Erratum: JHEP 10, 136 (2012)].
R. Dermisek and A. Raval, Phys. Rev. D 88 (2013) 013017.
G. Arcadi et al., Phys. Rev. Lett. 127 (2021), no. 6 061802.
C.-T. Lu et al., JHEP 08 (2021) 073.
G. Guedes and P. Olgoso, JHEP 09 (2022) 181.

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Minimal extension in the leptonic sector? → **2 Vector-Like Leptons** coupling to μ

	$SU(2)_L$	$U(1)_Y$	$U(1)_L$
ℓ_L	$\mathbf{2}$	$-1/2$	1
μ_R	1	1	1
H	$\mathbf{2}$	$+1/2$	0
N_R	1	1	1
S_R	1	1	-1
ψ_L	$\mathbf{2}$	$-1/2$	1
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Extended Seesaw

Small Symmetry Breaking Parameters

New!

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$$+ Y_R \overline{\psi_L} H \mu_R + Y_V \overline{S_R^c} \widetilde{H}^\dagger \psi_R + Y_V' \overline{\psi_L}\widetilde{H} N_R + M_\psi \overline{\psi_L}\psi_R + M_L \overline{\ell_L}\psi_R + \text{h.c.}\,,$$

$$\chi \equiv (\nu_L,\, N_R^c,\, S_R^c,\, \psi_L^0,\, \psi_R^{0c})^T$$

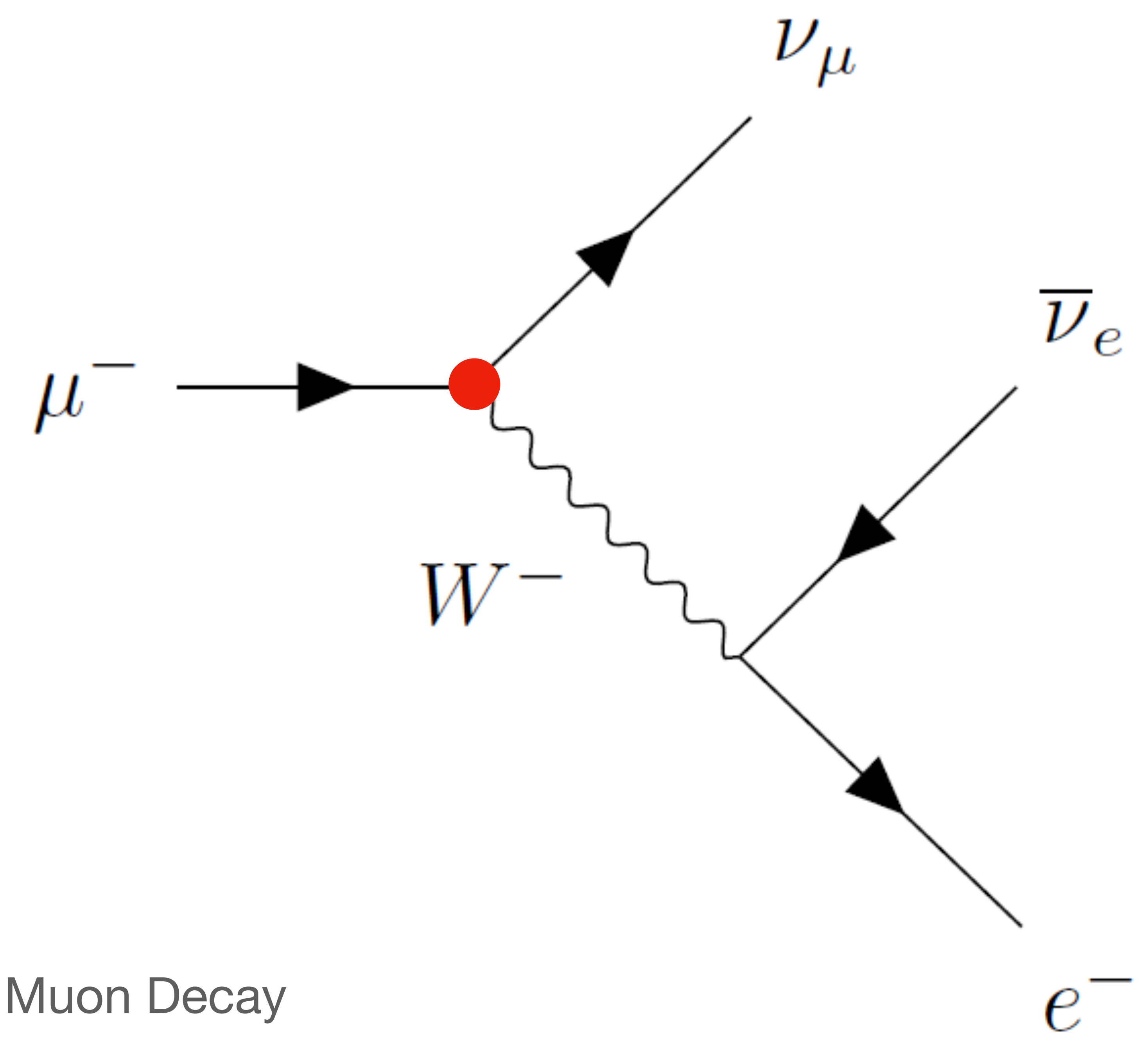
$$-\mathscr{L}_Y \supset \frac{1}{2}\overline{\chi}\mathcal{M}_\chi \chi^c$$

$$\mathcal{M}_\chi = \begin{pmatrix} 0 & m_N & \epsilon\, m_S & 0 & M_L \\ m_N & 0 & \Lambda & m_{V'} & 0 \\ \epsilon\, m_S & \Lambda & \mu & 0 & m_V \\ 0 & m_{V'} & 0 & 0 & M_\psi \\ M_L & 0 & m_V & M_\psi & 0 \end{pmatrix}$$

$$m_\nu \simeq \frac{v^2}{2}\left[\left(Y_N \frac{1}{\Lambda^T}\mu\frac{1}{\Lambda}Y_N^T\right) - \epsilon\left(Y_S\frac{1}{\Lambda}Y_N^T + Y_N\frac{1}{\Lambda^T}Y_S^T\right)\right]$$

M_W

M_W is computed from **three** input parameters: $G_F\,,\alpha_{em}\,,M_Z$



$$G_F = G_\mu(1+\Delta_G)$$

$$M_W = M_Z\sqrt{\frac{1}{2}+\sqrt{\frac{1}{4}-\frac{\pi\,\alpha\,(1-\Delta_G)}{\sqrt{2}\,G_\mu\,M_Z^2(1-\Delta r)}}}$$

$$\Delta_G \sim 5\times 10^{-3}$$

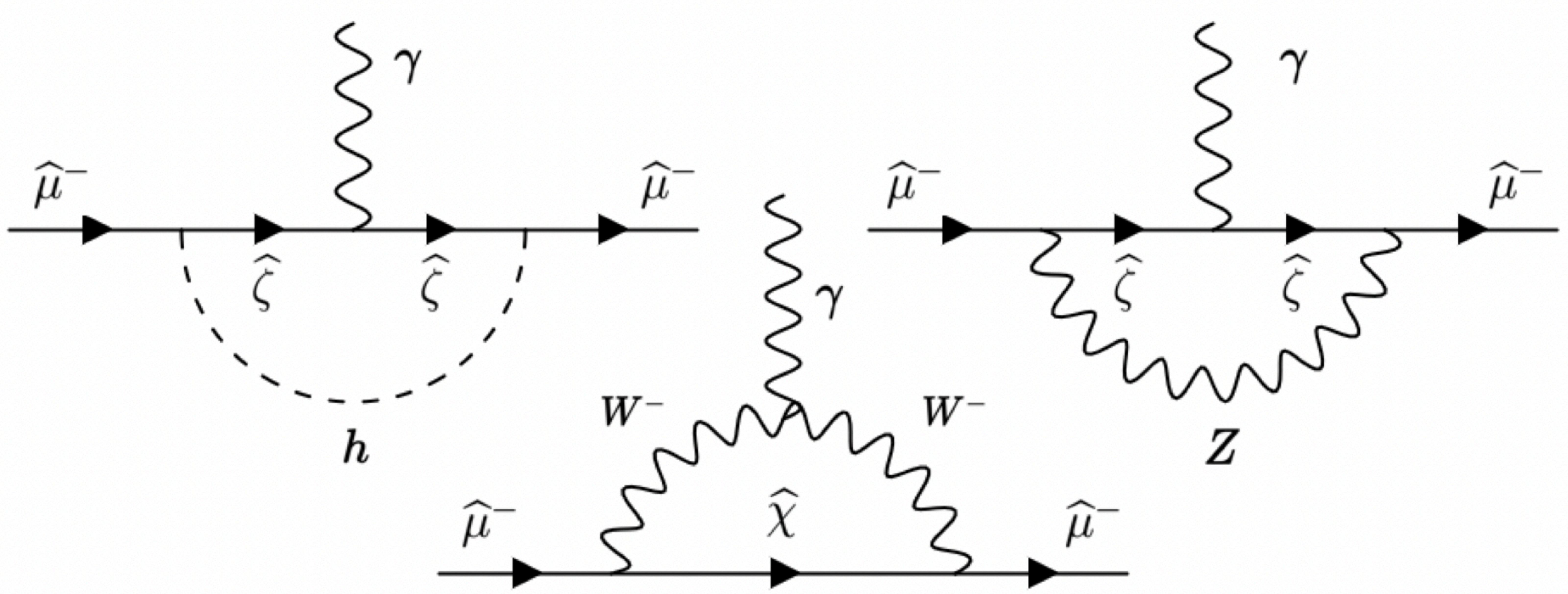
M. Blennow et al., Phys. Rev. D 106 (2022), no. 7 073005.
F. Arias-Aragon et al., JHEP 09 (2022) 210.

$(g-2)_\mu$

$$\frac{1}{2m_\ell}\bar{\ell}\sigma^{\mu\nu}\ell F_{\mu\nu}$$

Dimension-5 **LR** Operator
→ **mass insertion**

$\chi \equiv (\nu_L,\, N_R^c,\, S_R^c,\, \psi_L^0,\, \psi_R^{0c})^T\,, \qquad \zeta \equiv (\mu,\, \psi^-)^T$



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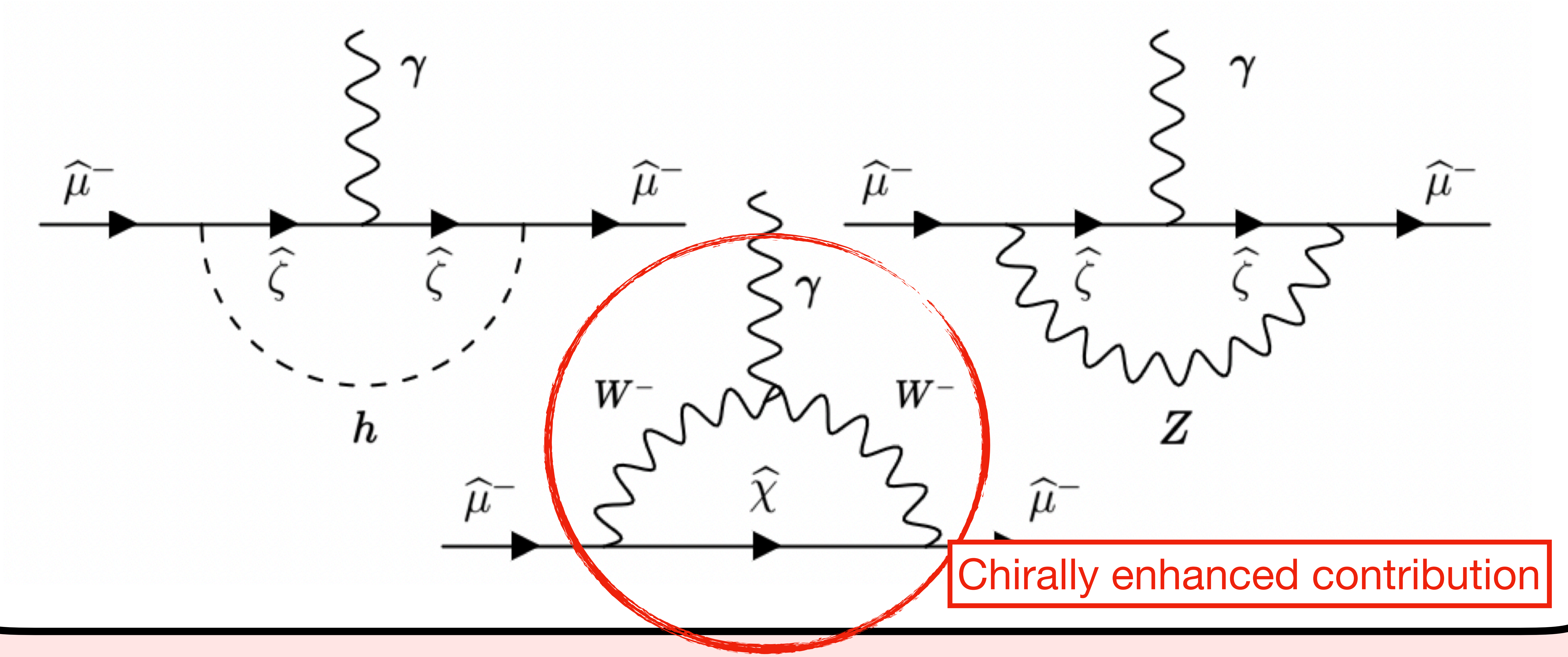

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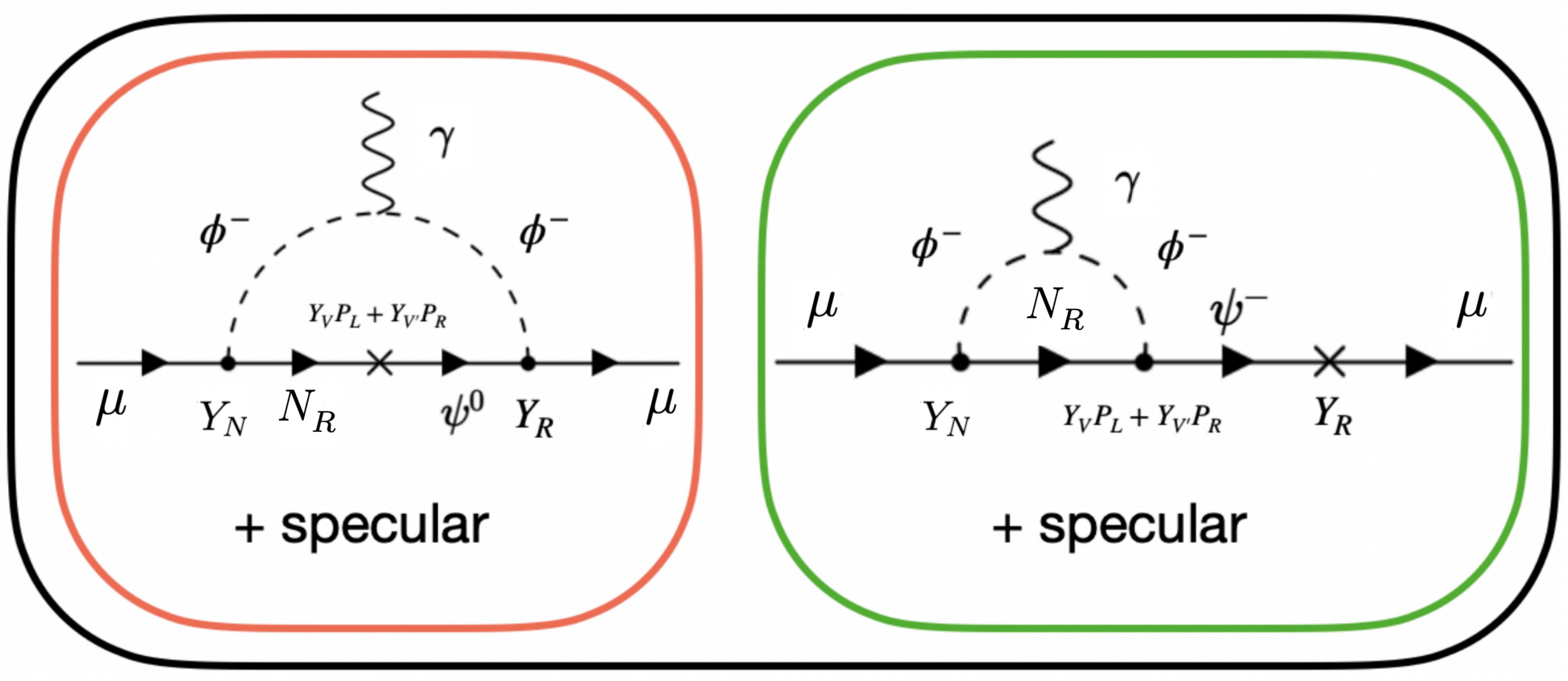
$(g-2)_\mu$

What to expect?

$$\delta a_\mu \sim \frac{Y_i^3}{16\pi^2}\frac{m_\mu}{v}\left[\mathcal{O}\left(\frac{v^2}{M_\psi \Lambda}\right)+\mathcal{O}\left(\frac{v^2}{M_\psi \Lambda}\right)^2\right]$$



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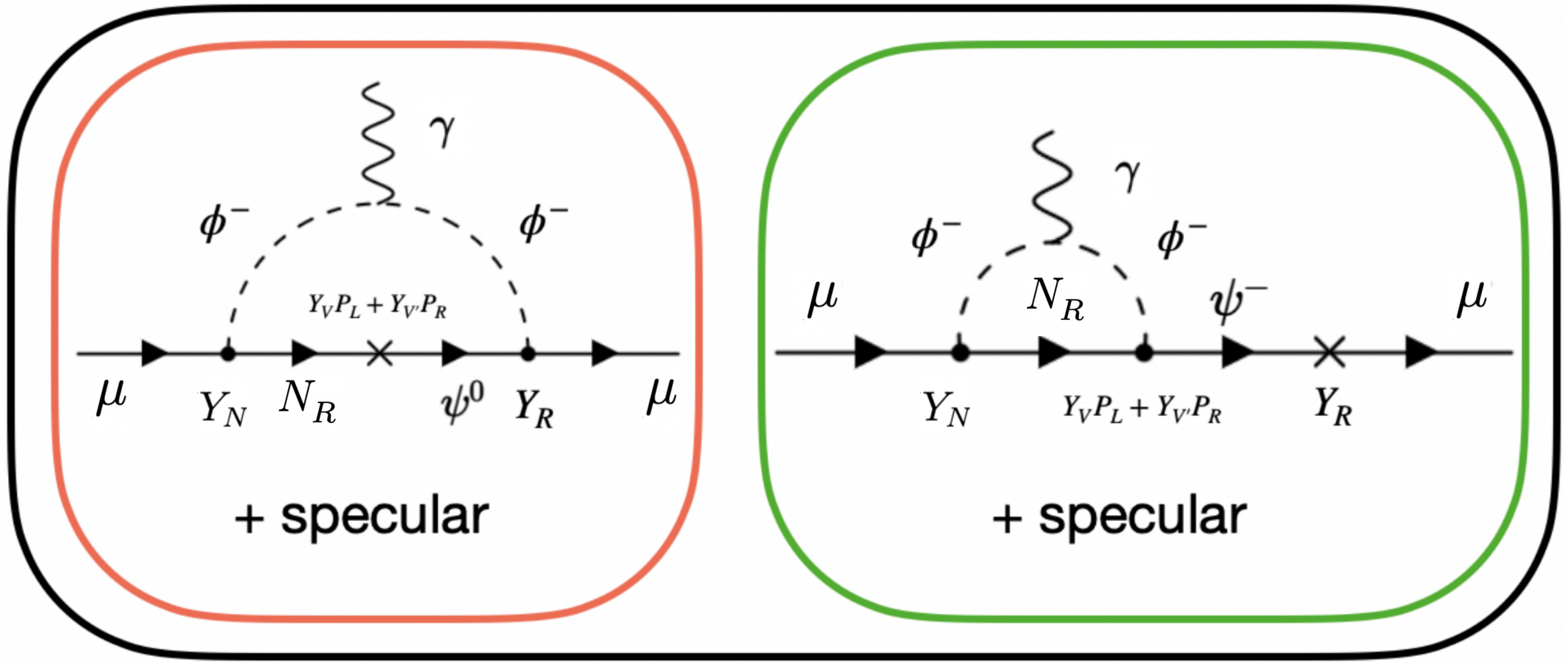
$$M_\psi, \Lambda \sim \mathcal{O}(10)\ \text{TeV}$$



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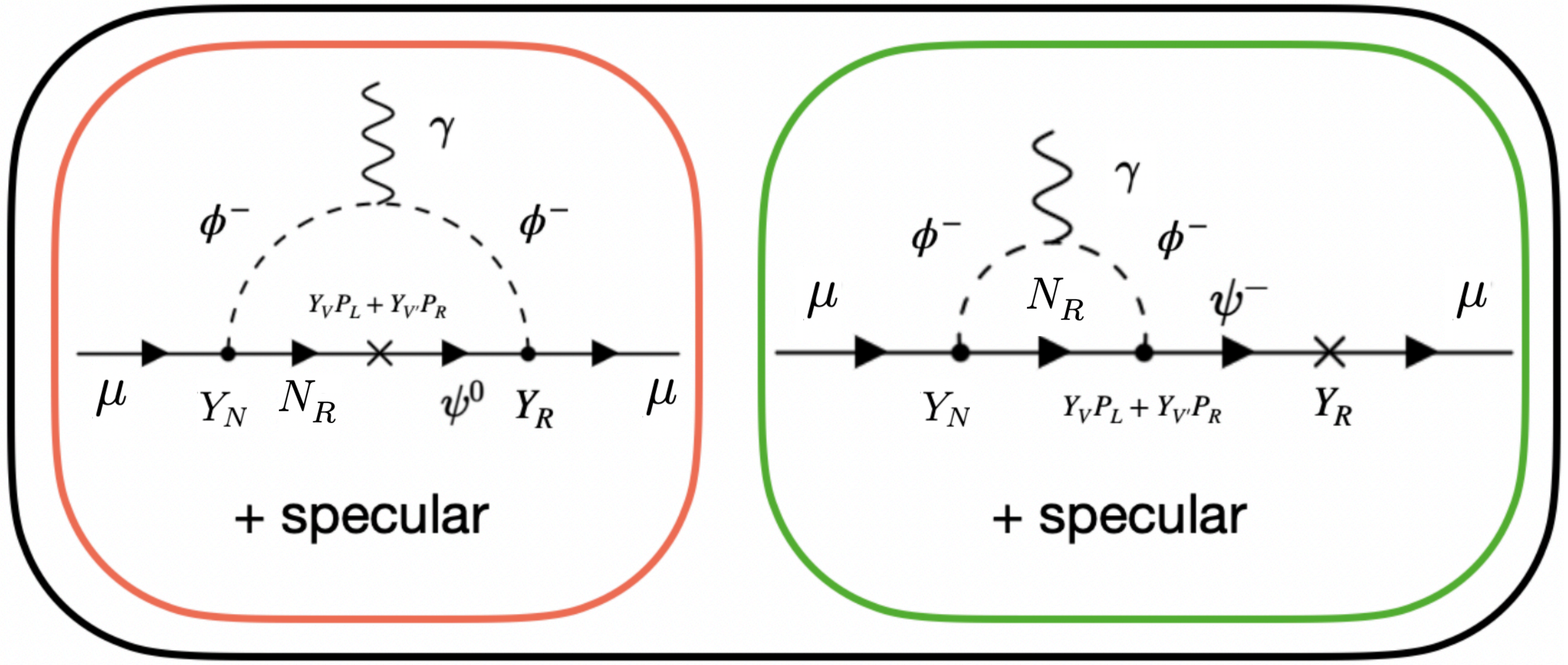
$M_\psi, \Lambda \sim \mathcal{O}(1)$ TeV

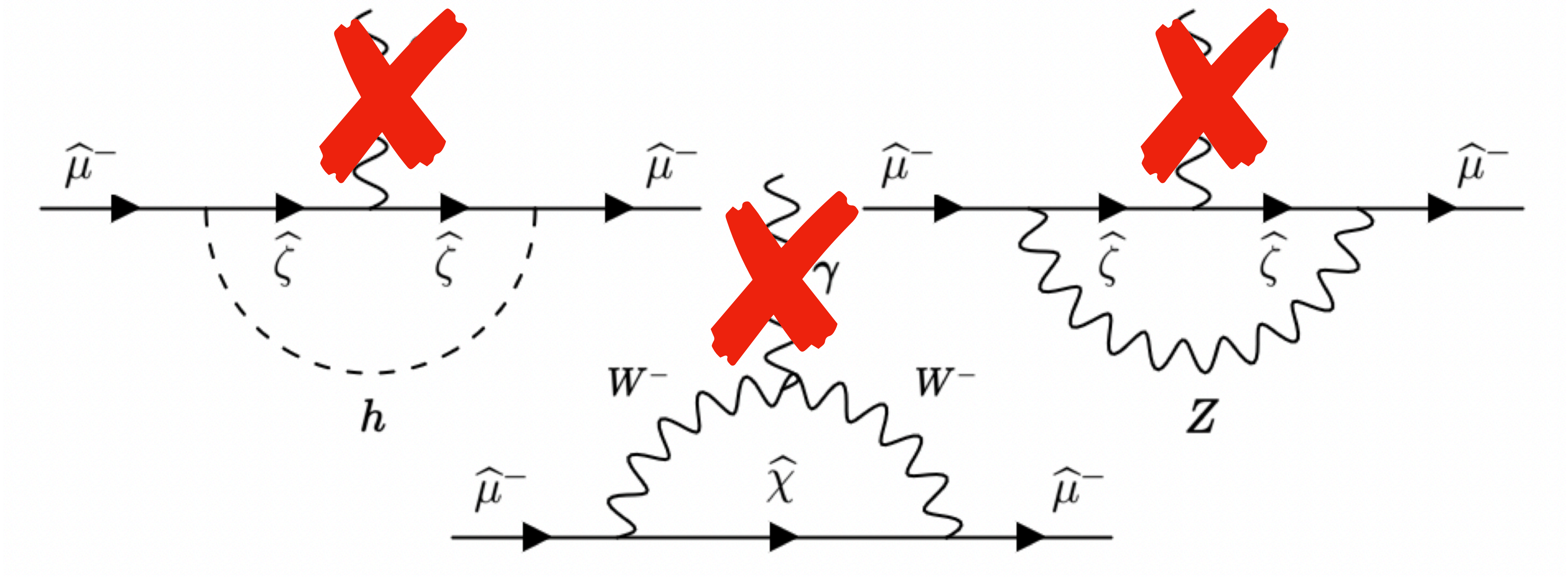


Accidental cancellation of the LO

$\longrightarrow$ violation of Wilsonian naturalness

N. Arkani-Hamed and K. Harigaya, JHEP 09 (2021) 025.
N. Craig et al., JHEP 05 (2022) 079.
L. Delle Rose et al., JHEP 05 (2022) 120.

Lepton masses radiatively?



$$\delta m_\mu \propto \delta a_\mu$$

Could this type of models be used for "**charged seesaws**" and generate the **lepton masses radiatively**?

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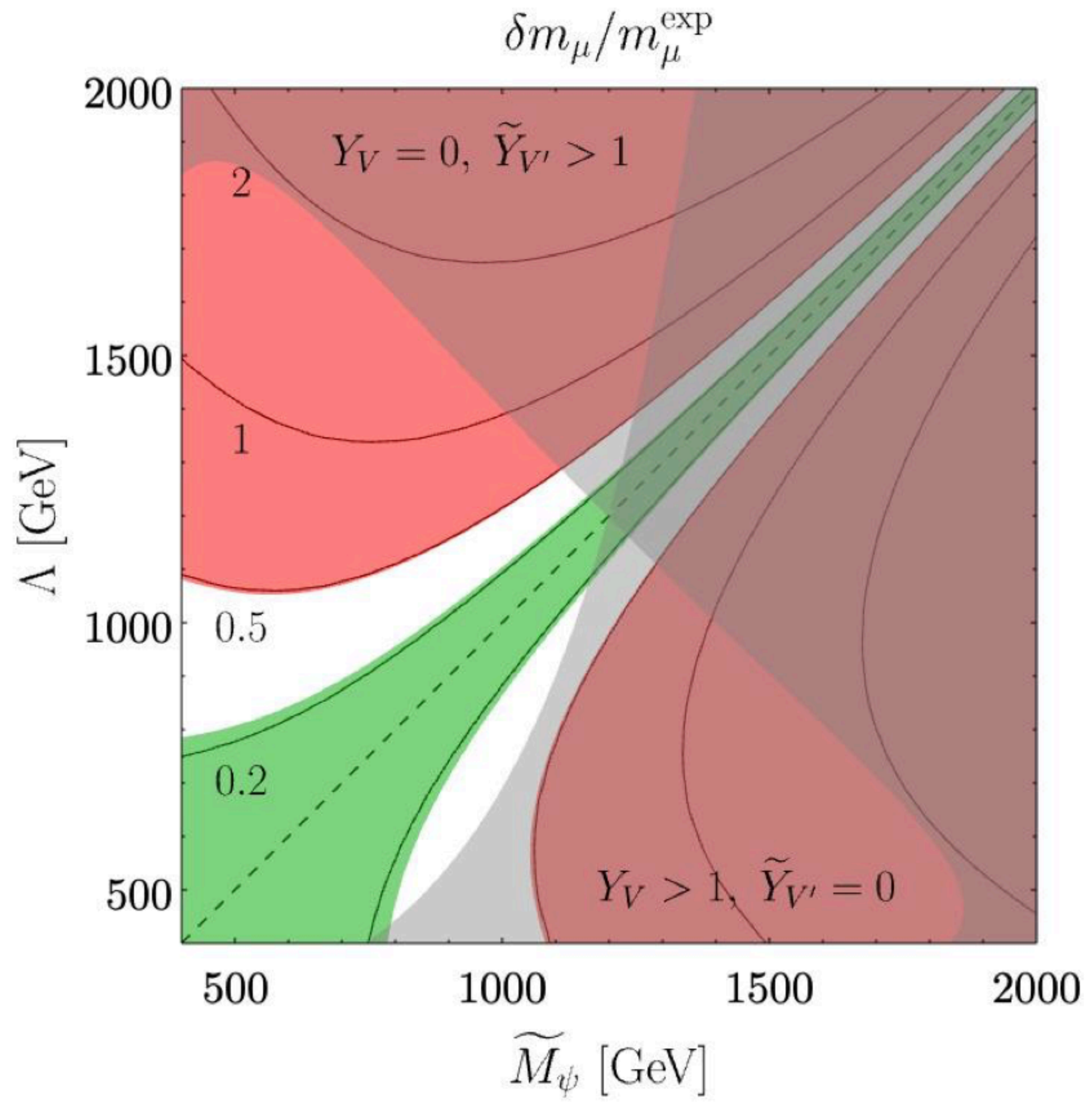
Parameter Space and Summary



$$m_\mu^{\text{exp}} = m_\mu^{\text{TL}} + \delta m_\mu$$

$$|\delta m_\mu| < 30\,\%\, m_\mu^{\text{TL}}$$

$$|\delta m_\mu| > |m_\mu^{\text{TL}}|$$

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Summary

- New particles:

2 HNLs +
Vector-Like
EW-Doublet

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Stay tuned!

Thanks!

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