GeV ALP from TeV Vector-like Leptons

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Based on 2402.14059, in collaboration with Arturo de Giorgi and Luca Merlo

Motivation

Objectives

- Active neutrino mass → Linear low scale seesaw [J. Kersten, A. Y. Smirnov, Phys. Rev. D 76 (2007) 073005] [A. Abada et al. JHEP 12 (2007) 061]
- Solve $(g-2)_\mu$ anomaly [T. Aoyama et. al., Phys. Rept. 887 (2020) 1–166]

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[A. de Giorgi, L. Merlo, S. Pokorski, Fortsch. Phys. 71 (2023), no. 4-5 2300020]

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- Two RH lepton singlets N, S
- EW Vector-like doublet ψ

} Neutral part = HNLs

- $\mathcal{U}(1)_{PQ}$ symmetry → ALP

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$$
\begin{aligned}
-\mathcal{L}_Y =& Y_N \overline{\ell_L} \widetilde{H} N_R + Y_R \overline{\psi_L} H \mu_R + \\
&+ \delta_{x,0} \Lambda \overline{N_R^c} S_R + \delta_{|x|,1} \alpha_N \phi^{(*)} \overline{N_R^c} S_R + \delta_{y,0} M_\psi \overline{\psi_L} \psi_R + \delta_{|y|,1} \alpha_\psi \phi^{(*)} \overline{\psi_L} \psi_R + \\
&+ Y_V \overline{S_R^c} \widetilde{H}^\dagger \psi_R + Y_{V'} \overline{\psi_L} \widetilde{H} N_R + \epsilon Y_S \overline{\ell_L} \widetilde{H} S_R + \mathrm{h.c}
\end{aligned}
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Only 2nd generation of leptons

$$
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\end{aligned}
$$

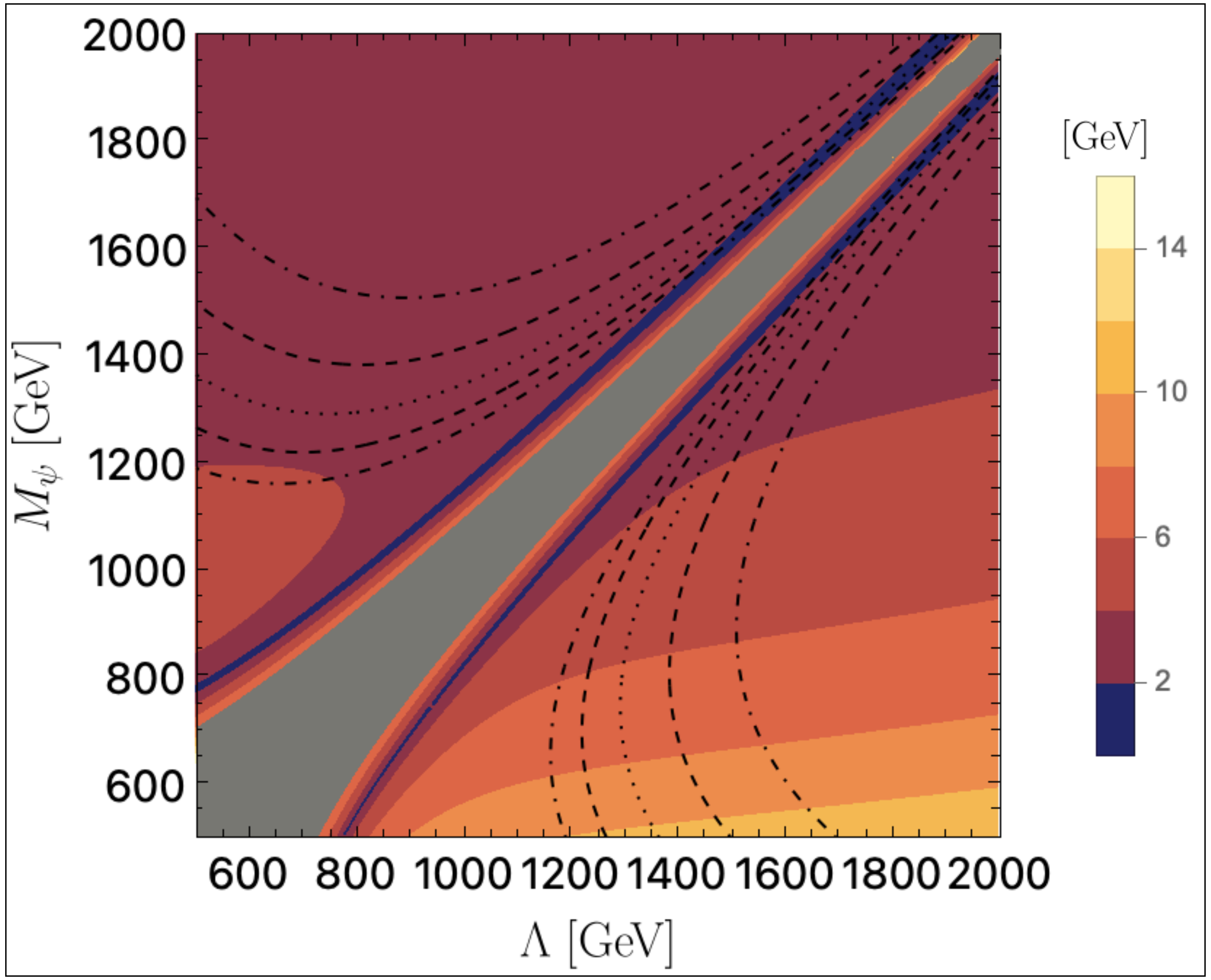
ALP phenomenology

Specific model "Model B" $\left\{ \begin{array}{c} \Lambda \overline{N_R^c} S_R \\ + \\ \phi^{(*)} \psi_L \psi_R \end{array} \right.$

ALP mass

$$m_a^2 \propto Y_V Y_{V'} \Lambda M_\psi$$

m_a



$Y_V = 0.1$

ALP phenomenology

Specific model "Model B"

$$\Lambda \overline{N_R^c} S_R + \phi^{(*)} \psi_L \psi_R$$

ALP mass

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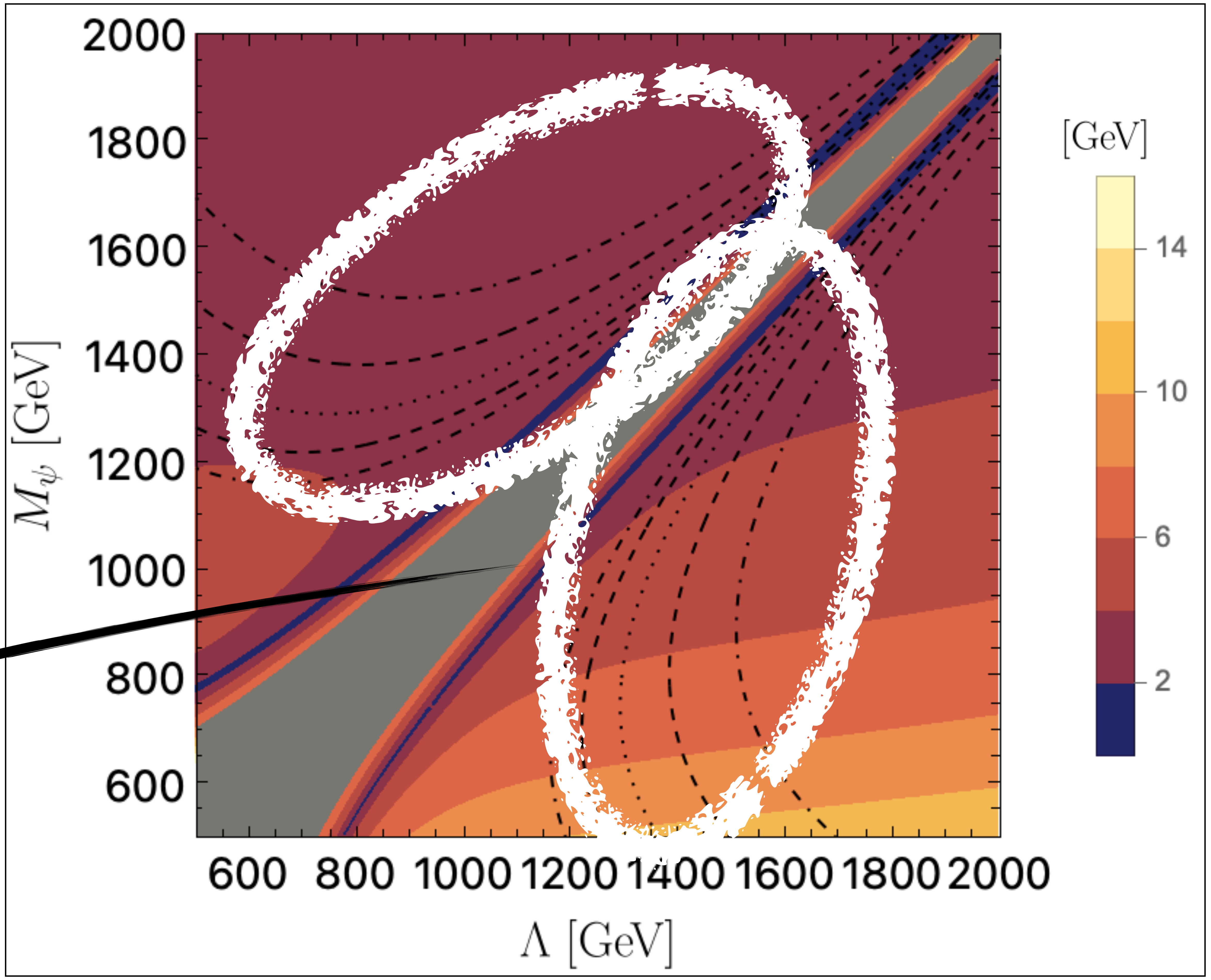
Solution to $(g-2)_\mu$!

m_a



$Y_V = 0.1$

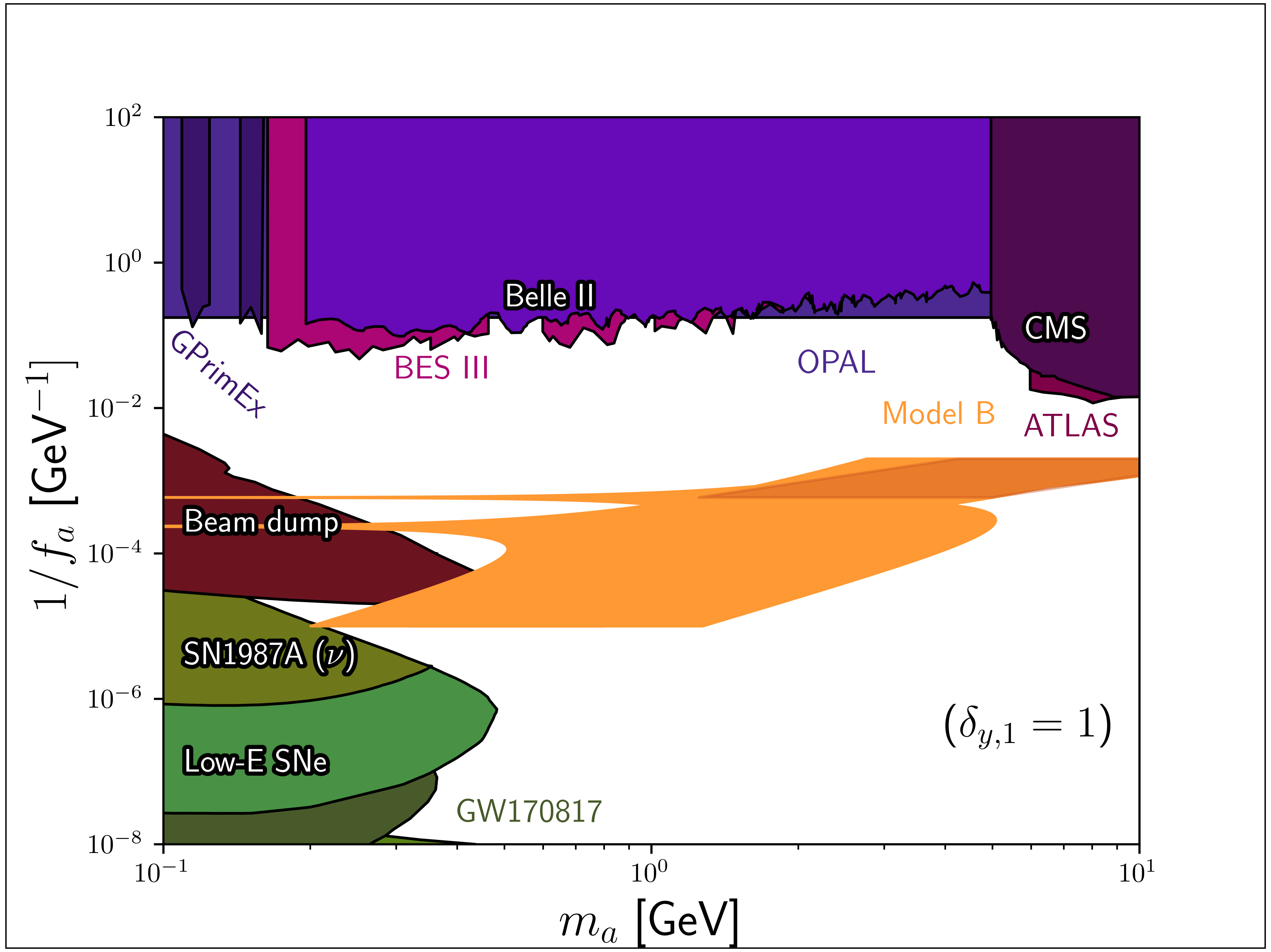
Coupling to SM particles

W, Z, γ, charged particles →
Calculated at 1-loop

Coupling to photons

$$g_{a\gamma\gamma} = \bar{\delta}_{y,1} \frac{\alpha_{\rm em}}{\pi f_a}$$

Not excluded ⇒ Testable!



Adapted from **Ciaran O'Hare,** https://cajohare.github.io/AxionLimits/

Conclusions

UV completion with **exotic lepton sector**

- Realistic **mass** for active **neutrinos**
- Viable solution to $(g-2)_\mu$
- TeV-scale HNLs and GeV-mass ALP with scale $\mathcal{O}(TeV)$

TESTABLE AT COLLIDERS

Thank you for your attention

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AGENCIA ESTATAL DE INVESTIGACIÓN
EXCELENCIA SEVERO OCHOA
COSMIC WISPERS CA21106

Lagrangian of the model

$$[SU(2)_L \times U(1)_Y]_{\text{gauge}} \times [U(1)_{LN} \times U(1)_{PQ}]_{\text{global}}$$

$$\begin{aligned}-\mathcal{L}_Y = & Y_N \overline{\ell_L} \widetilde{H} N_R + Y_R \overline{\psi_L} H \mu_R + \\ & + \delta_{x,0} \Lambda \overline{N_R^c} S_R + \delta_{|x|,1} \alpha_N \phi^{(*)} \overline{N_R^c} S_R + \delta_{y,0} M_\psi \overline{\psi_L} \psi_R + \delta_{|y|,1} \alpha_\psi \phi^{(*)} \overline{\psi_L} \psi_R + \\ & + Y_V \overline{S_R^c} \widetilde{H}^\dagger \psi_R + Y_{V'} \overline{\psi_L} \widetilde{H} N_R + \epsilon Y_S \overline{\ell_L} \widetilde{H} S_R + \text{h.c}\end{aligned}$$

	$\Lambda \overline{N_R^c} S_R$	$\phi^{(*)} \overline{N_R^c} S_R$
$M_\psi \overline{\psi_L} \psi_R$		Model A
$\phi^{(*)} \overline{\psi_L} \psi_R$	Model B	Model C and D

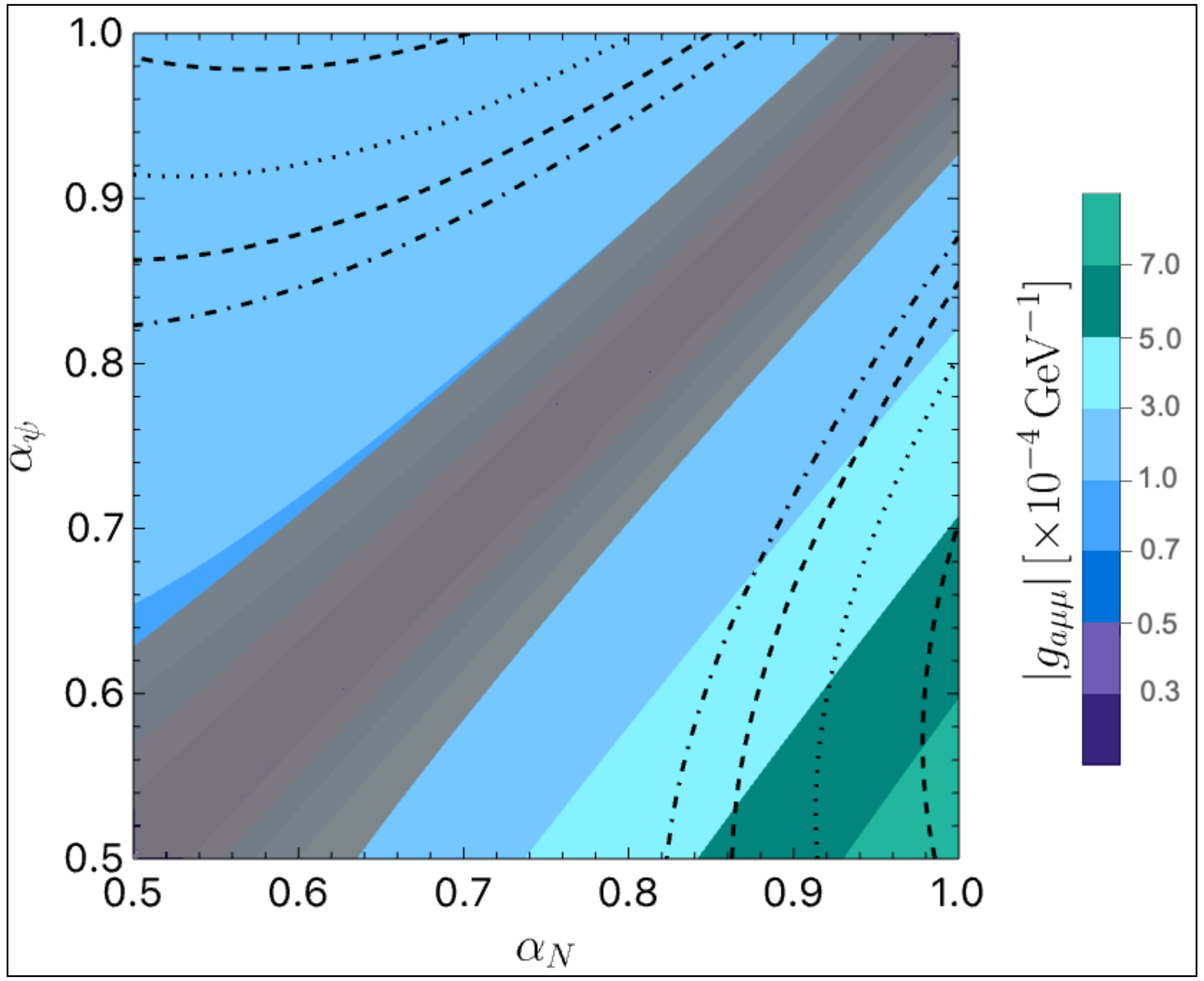
Couplings to SM

$$g_{aWW} = \bar{\delta}_{y,1}\frac{\alpha_{\rm em}}{2\pi f_a s^2_{\theta_W}}$$

$$g_{aZZ} = \bar{\delta}_{y,1}\frac{\alpha_{\rm em}}{6\pi f_a s^2_{2\theta_W}}\left(c_{4\theta_W}+7\right)$$

$$f_a \sim \mathcal{O}(1)\ \text{GeV}$$

$$g_{a\mu\mu} = \frac{(\bar{\delta}_{x,1}+\bar{\delta}_{y,1})}{f_a}\times\left(\frac{Y_V}{Y_V+\left(\frac{M_\psi}{\Lambda}\right)Y_{V'}}\right)$$

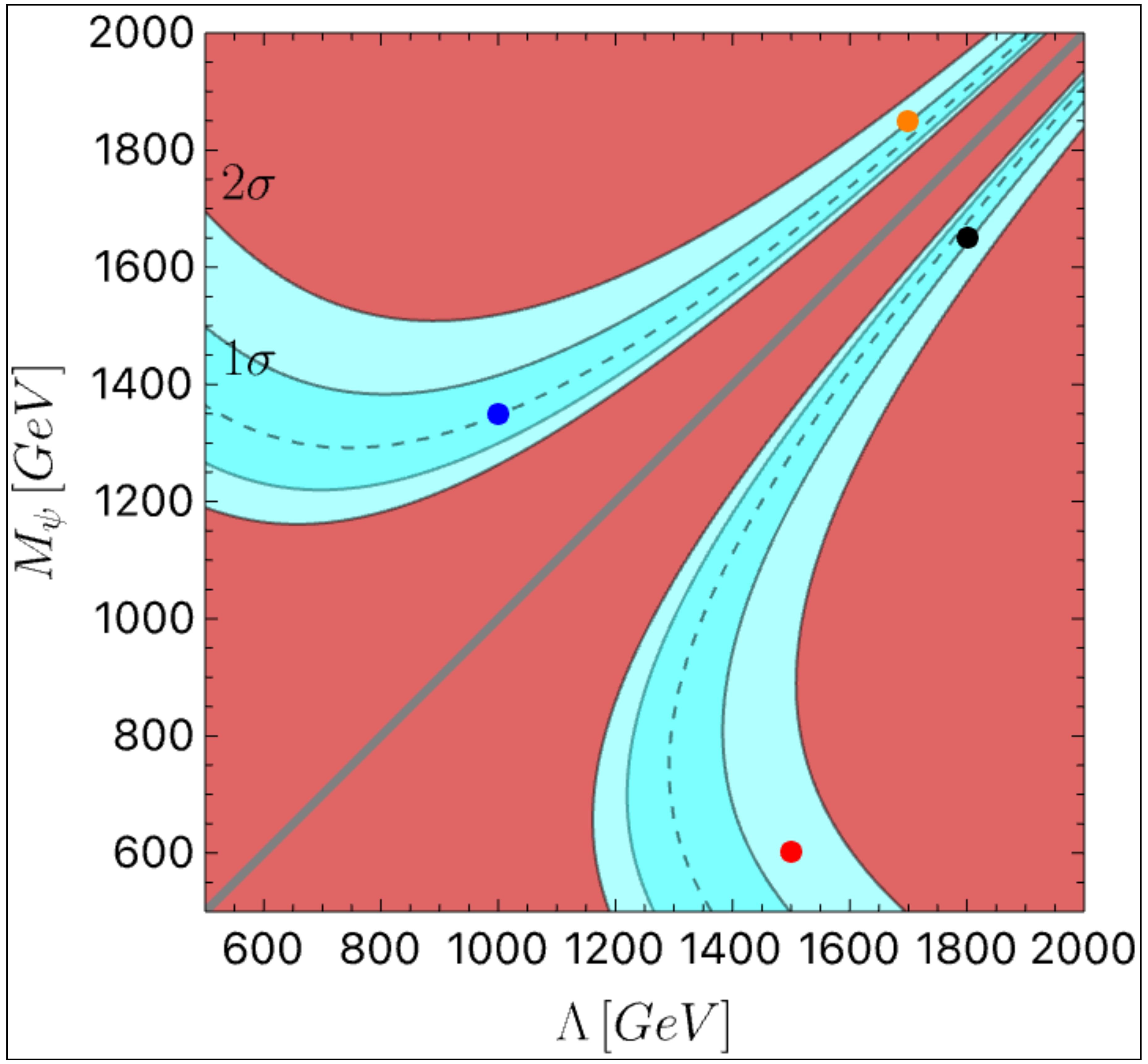


$Y_V = 0.4$

$(g-2)_\mu$ and μ mass

$$\delta a_\mu = \frac{3\, m_\mu^{\exp}}{4\,\pi^2\, v^2} \frac{M_W^2}{\Lambda M_\psi} \frac{m_N m_R}{M_\psi} \left(\frac{m_V}{M_\psi} + \frac{m_{V'}}{\Lambda} \right) F_0 \left(\frac{\Lambda^2}{M_W^2}, \frac{M_\psi^2}{M_W^2} \right)$$

$$F_0(x,y) \equiv \frac{3}{2} - \frac{x \log y - y \log x}{x - y}$$

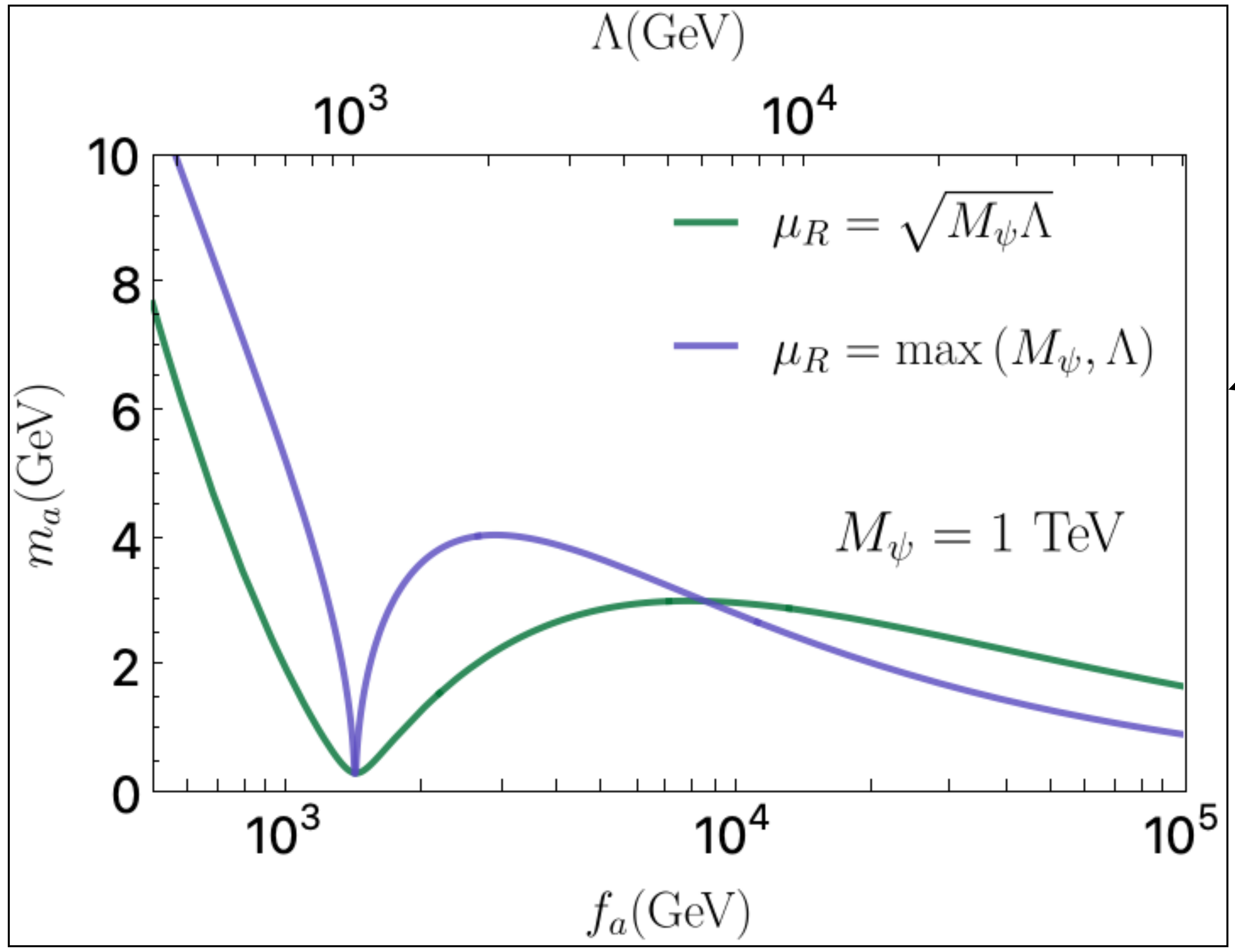


ALP mass

$$V_{\rm CW} = -\frac{1}{32\pi^2}\left\{ \mathrm{Tr}\left[\left(\mathcal{M}_\chi \mathcal{M}_\chi^\dagger\right)^2 \log\left(\frac{\mathcal{M}_\chi \mathcal{M}_\chi^\dagger}{\mu_R^2}\right)\right] - \frac{3}{2}\mathrm{Tr}\left[\left(\mathcal{M}_\chi \mathcal{M}_\chi^\dagger\right)^2\right]\right\}$$

Coleman-Weinberg potential, from [A. de Giorgi, L. Merlo, X. Ponce Díaz, S. Rigolin, 2312.13417]

$$f_a^2 m_a^2 = \frac{(\bar\delta_{x,1}+\bar\delta_{y,1})^2}{4\pi^2}\left(\frac{m_V m_{V'}\Lambda M_\psi}{M_\psi^2-\Lambda^2}\right)\left[\frac{(M_\psi^2+\Lambda^2)}{2}\log\left(\frac{M_\psi^2}{\Lambda^2}\right) + (M_\psi^2-\Lambda^2)\left(\log\left(\frac{M_\psi \Lambda}{\mu_R^2}\right)-1\right)\right]$$



Renormalization scale dependence

Scale dependence