GeV ALP from TeV Vector-like Leptons

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based on 2402.14059 in collaboration with Arturo de Giorgi and Luca Merlo

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Motivation

UV COMPLETION

- **GeV mass** for the ALP
- **Coupling of ALP to muons** spanning over several orders of magnitude
- Solves the $(g-2)_\mu$ **anomaly**

Key ingredients:

- **Linear low scale seesaw** with **HNLs** $\Rightarrow$ Neutrino masses
- Exotic **vector-like lepton doublet** of $SU(2)$
- Additional $U(1)_{PQ}$ **symmetry**

} arXiv:2211.03797, A. de Giorgi, L. Merlo, S. Pokorski

Lagrangian of the model

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

MAIN FEATURES

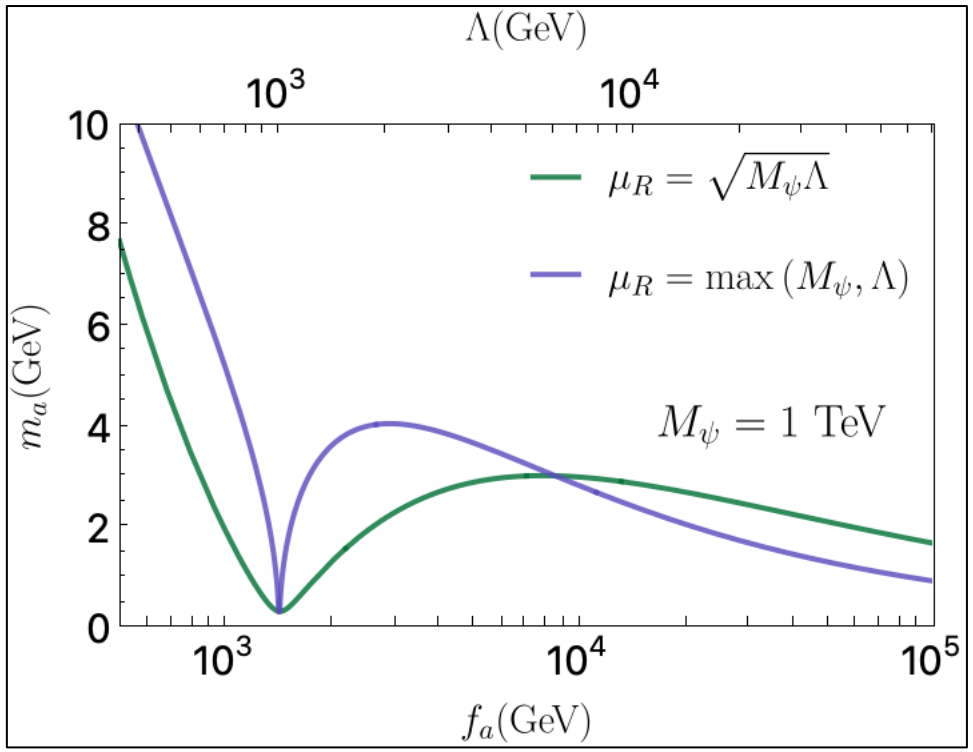
- Mass of heavy leptons can be generated **dynamically by SSB**
- **No muon mass** at tree level

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

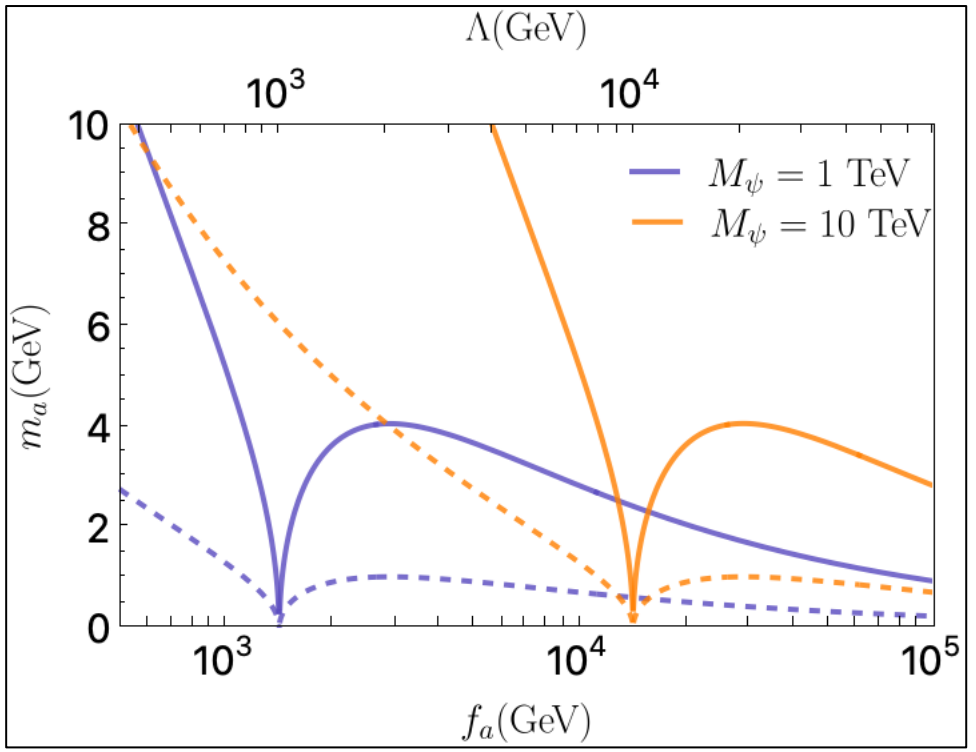
ALP mass

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

Dependence on renormalization scale



Dependence on Yukawa and M_ψ



Model A

$$M_\psi \overline{\psi_L} \psi_R$$

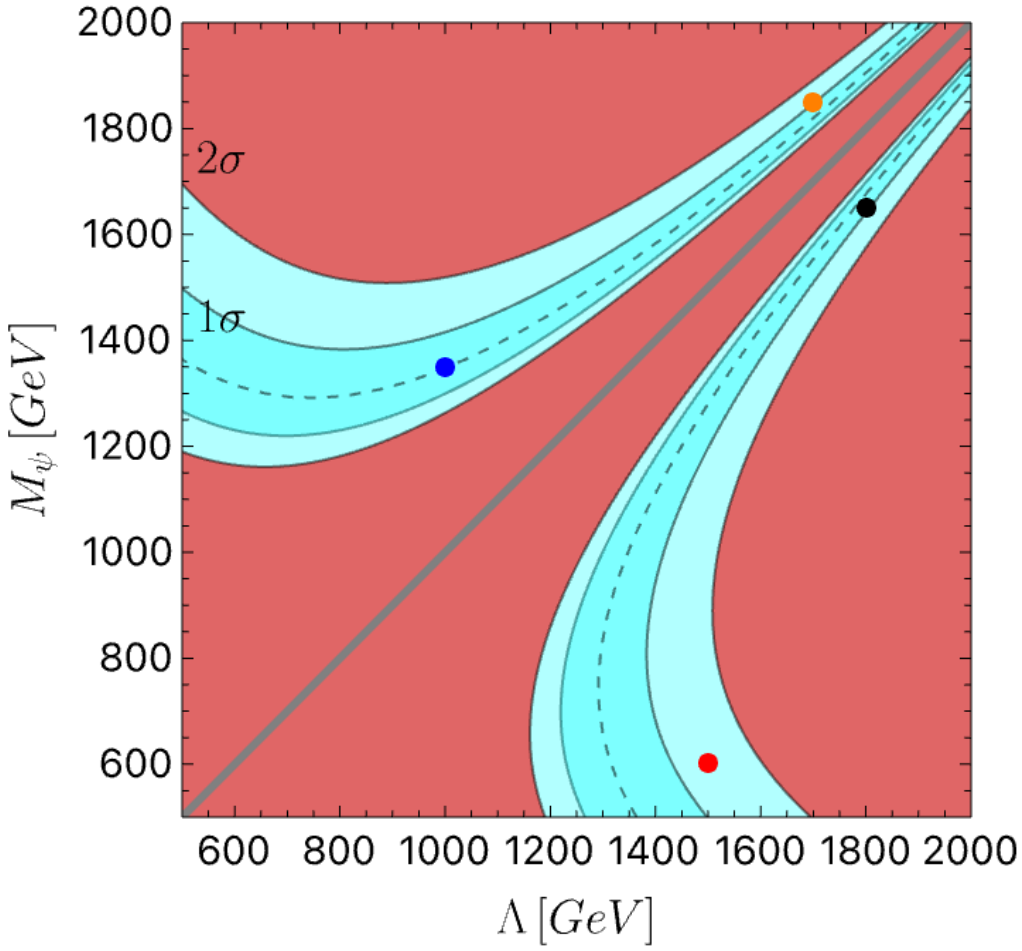
+

$$\phi^{(*)} \overline{N_R^c} S_R$$

Muon mass

- Parameter space of Λ vs. M_ψ
- Grey line represents vanishing muon mass (large Yukawa)
- Model independent

Muon mass and $(g-2)_\mu$ can be explained simultaneously



Coupling to bosons

Photons

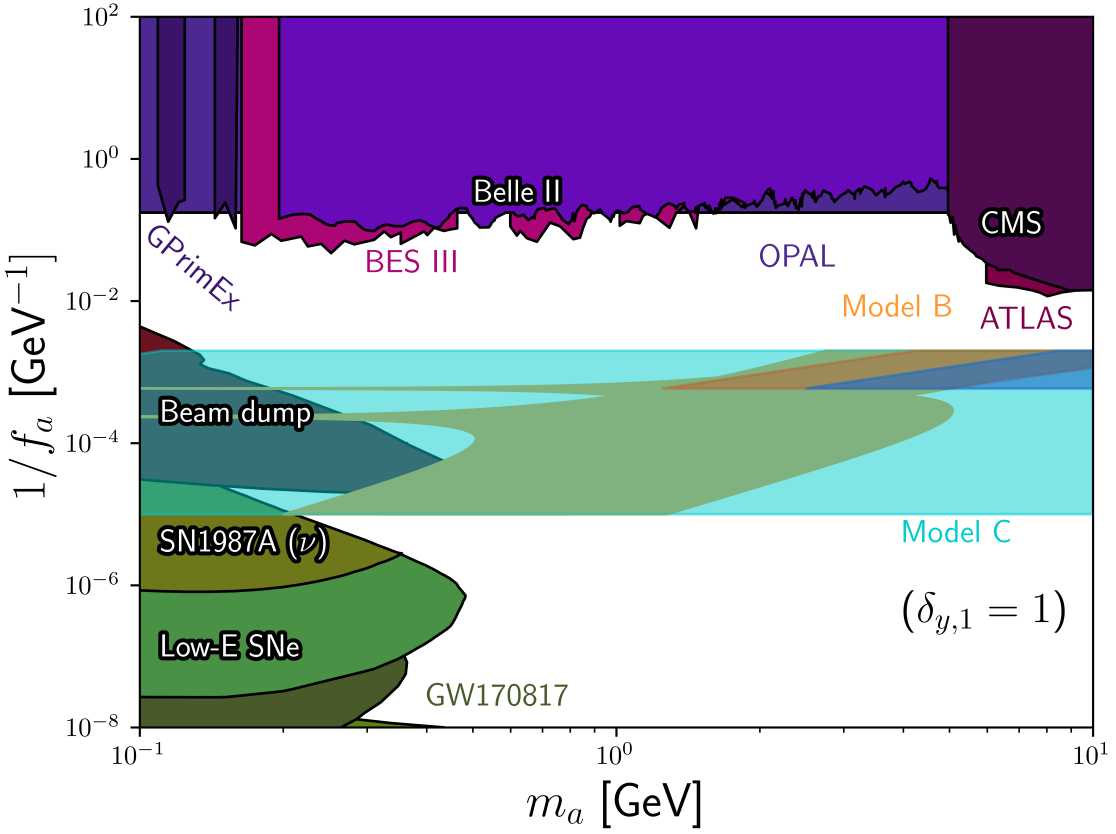
$$g_{a\gamma\gamma} = \overline{\delta}_{y,1} \frac{\alpha_{\rm em}}{\pi f_a}$$

Z and W bosons

$$g_{aVV} \propto \frac{1}{f_a} \Rightarrow f_a \sim \mathcal{O}(1)\ \text{GeV}$$

arXiv: 2202.03450 , J.Bonilla, I.Brivio, J. Machado-Rodríguez, J.F. Trocóniz

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



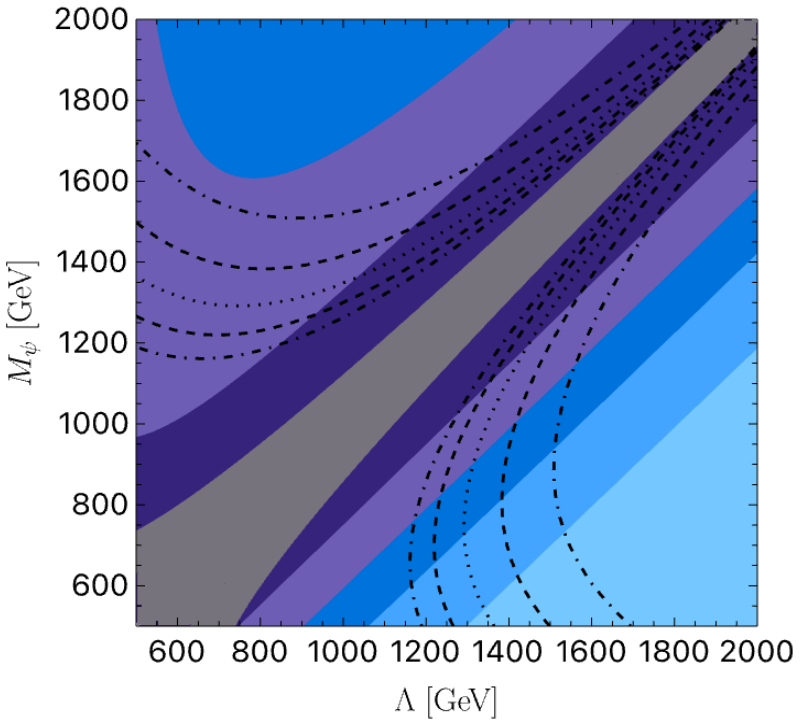
Coupling to muons

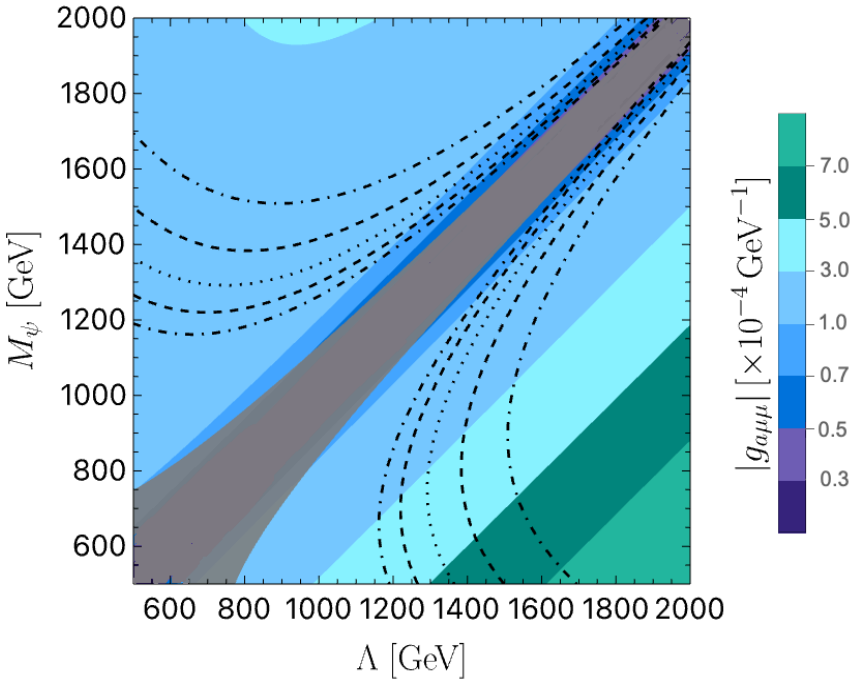
$$g_{a\mu\mu} = \frac{(\overline{\delta}_{x,1} + \overline{\delta}_{y,1})}{f_a} \times \left(\frac{Y_V}{Y_V + \left(\frac{M_\psi}{\Lambda}\right) Y_{V'}} \right)$$

ORIGIN

- Rotation to mass basis
- 1-loop diagram

$Y_V = 0.1$





$Y_V = 0.5$

Summary plots

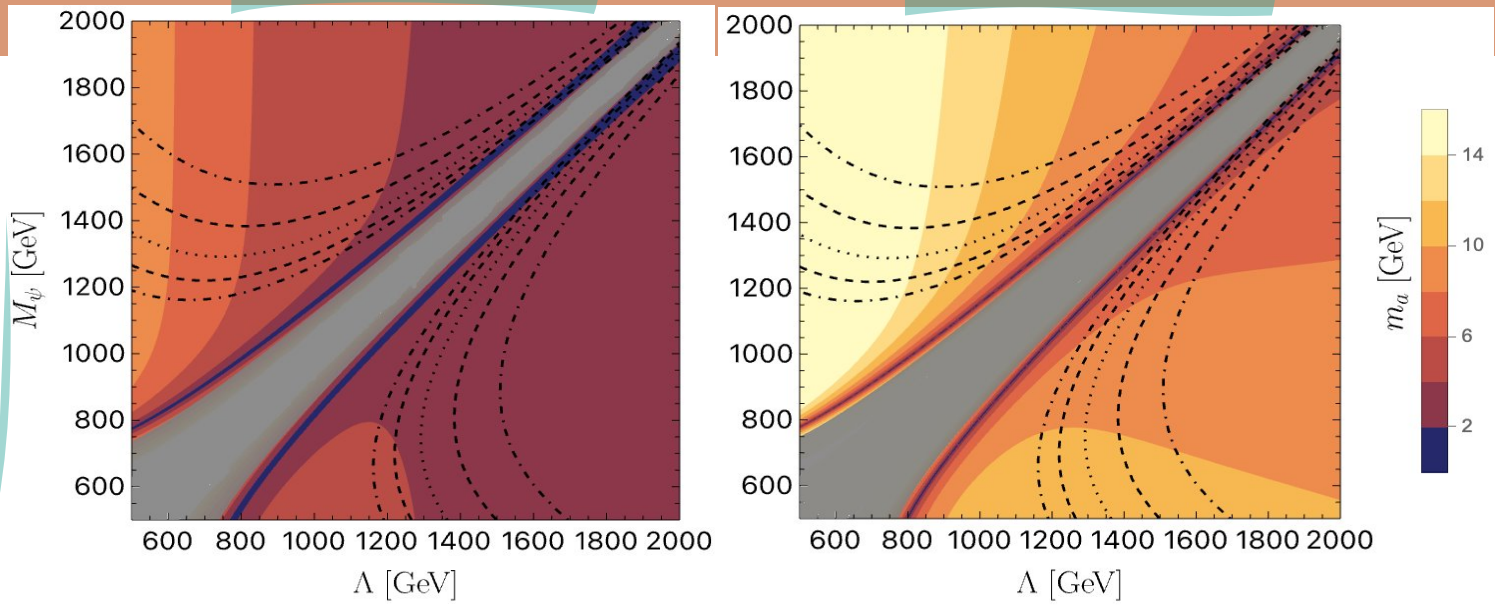
Model B just like A with specular symmetry

Possible to generate GeV ALP mass

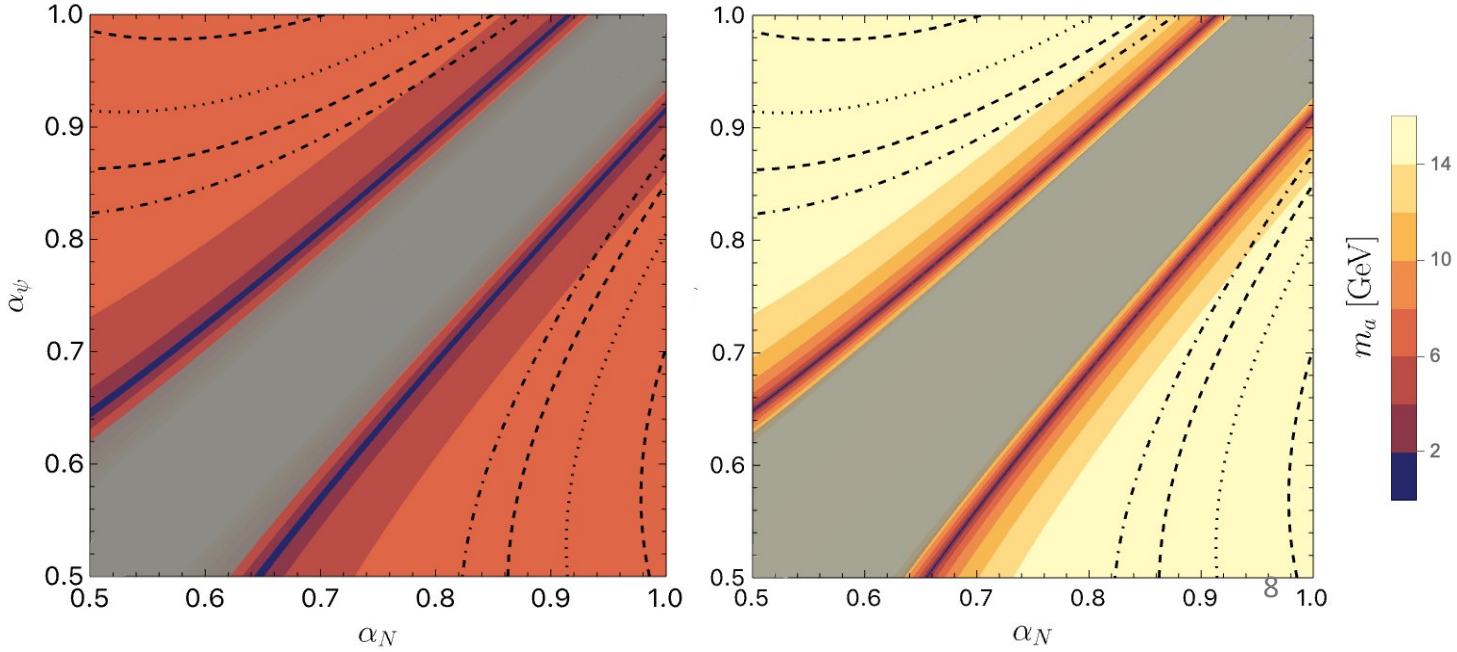
$Y_V = 0.1$

$Y_V = 0.5$

Model A



Model C



$f_a = 2\ TeV$

Conclusions

UV completion that:

- Possible explanation to the $(g-2)_\mu$ **anomaly**
- **ALP masses** of $\mathcal{O}(GeV)$
- **ALP-muon coupling** expands over several orders of magnitude
- Possible to **test at colliders**

Thank you for your attention

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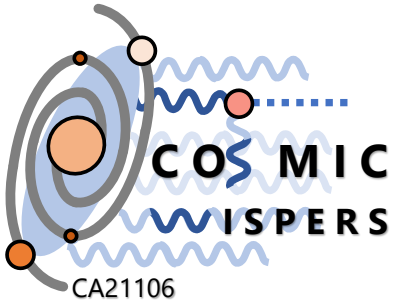
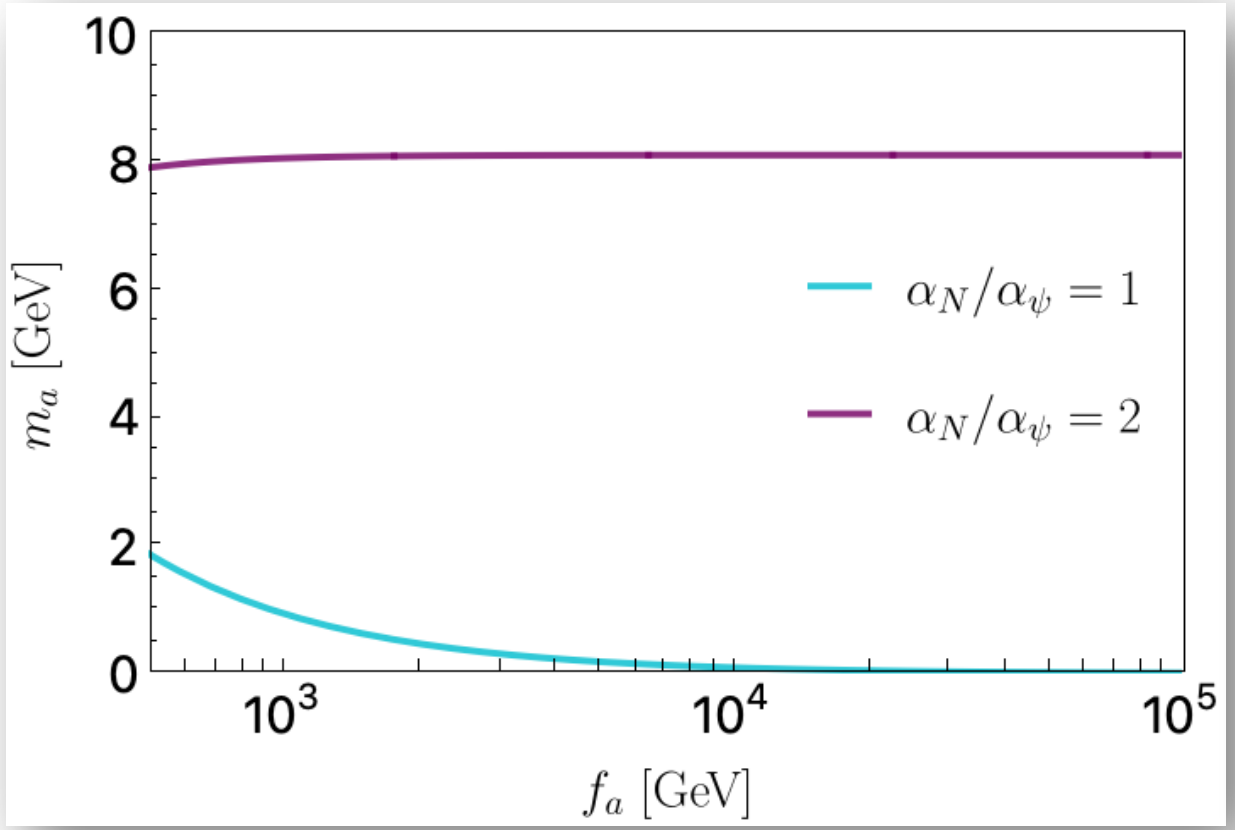
founded by



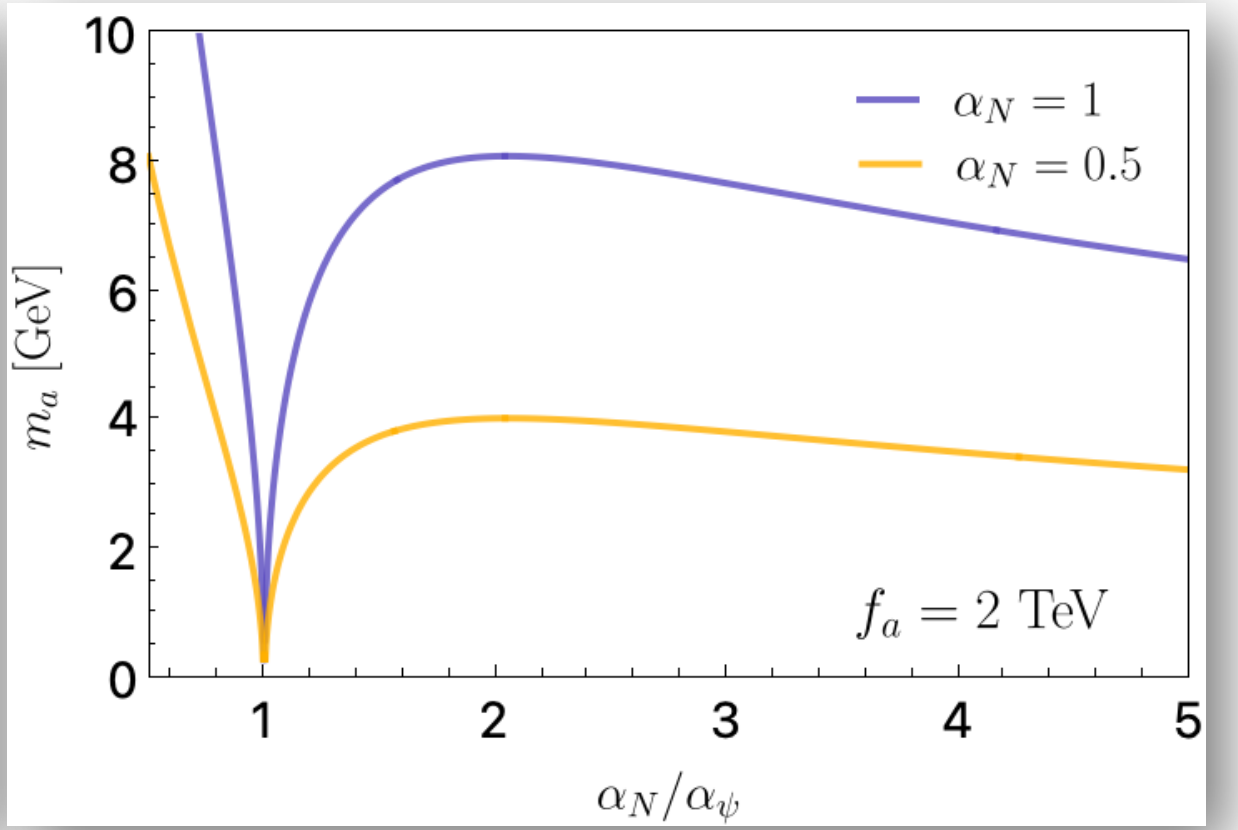
Back-up slides

Model C

Dependence on PQ scale



Dependence on ratio of coefficients



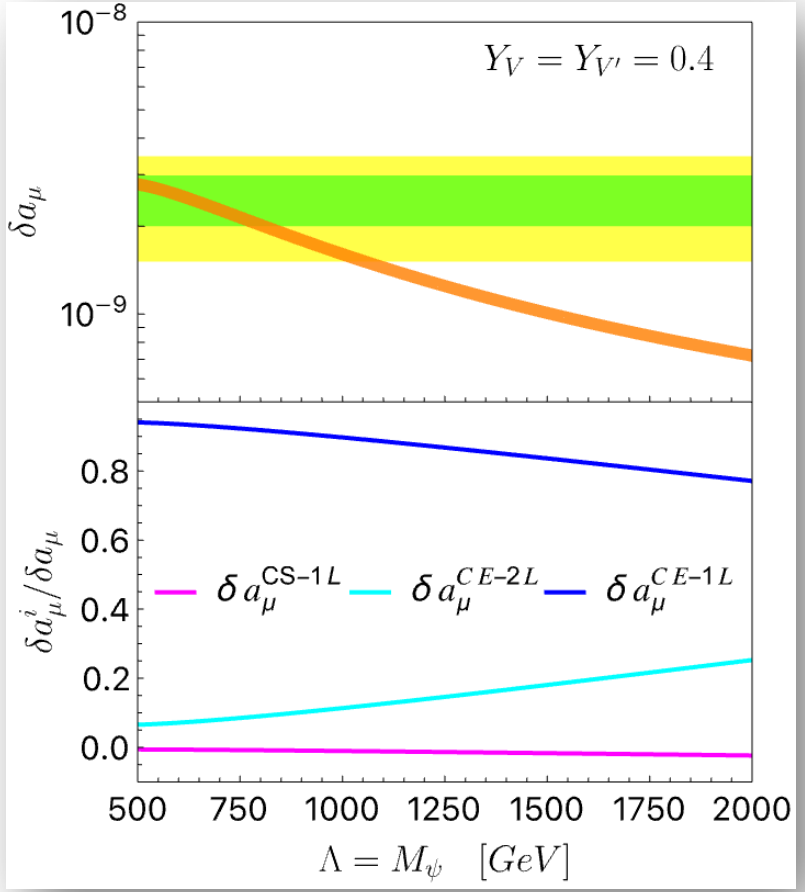
EW contributions

Chirally enhanced contribution at 1-loop

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

Loop function

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

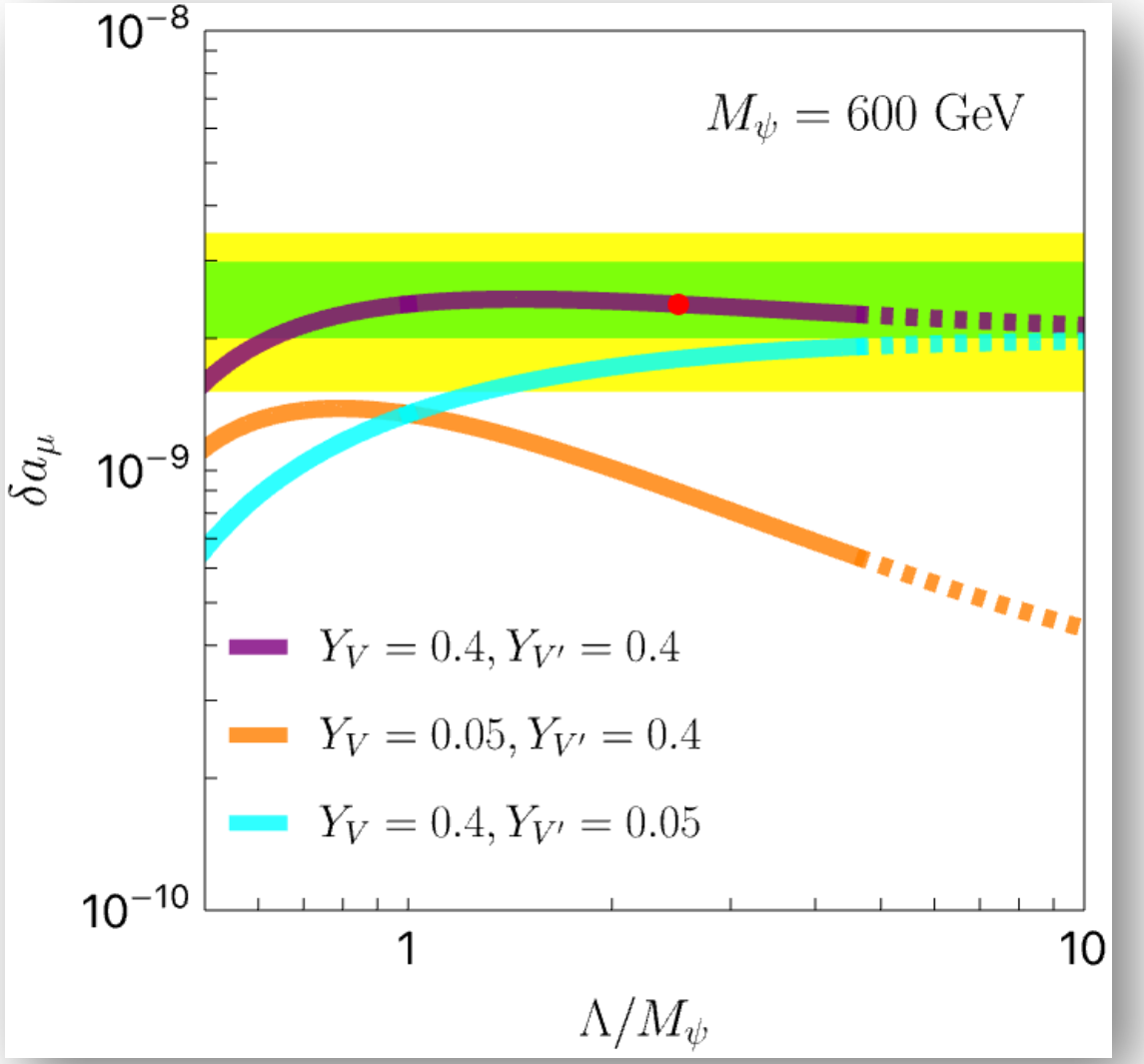


And the ALP?

$$\delta a_\mu^{\rm naive} \propto \frac{(m_\mu^{\rm exp})^2 m_R^2}{\alpha_\psi^2\, f_a^4}$$

→ Extra chiral suppression NOT considered

Dependence on the model parameters



δa_μ as a function of Λ/M_ψ

- Fixed M_ψ
- Fixed Yukawa values
- Model-independent

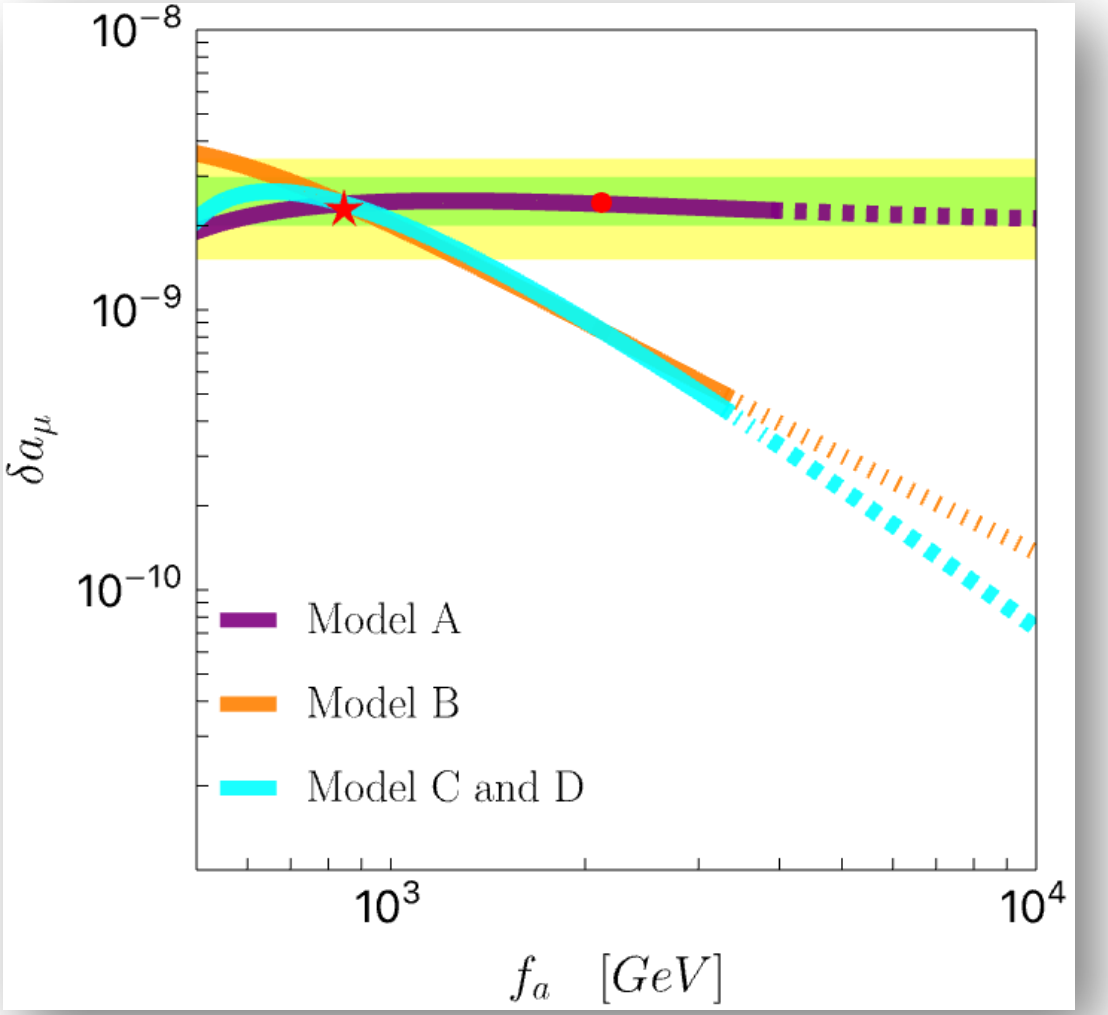
Possible to reach 2σ for some values

Dependence on the model parameters

δa_μ as a function of scale

- Different models studied
- Fixed Yukawa values

Model A solves it in full parameter space



Coupling to muons

$$\mathcal{L}_a \supset i\overline{\delta}_{y,1}\alpha_\psi \frac{a}{f_a}\overline{\psi_L}\psi_R$$

ORIGINS

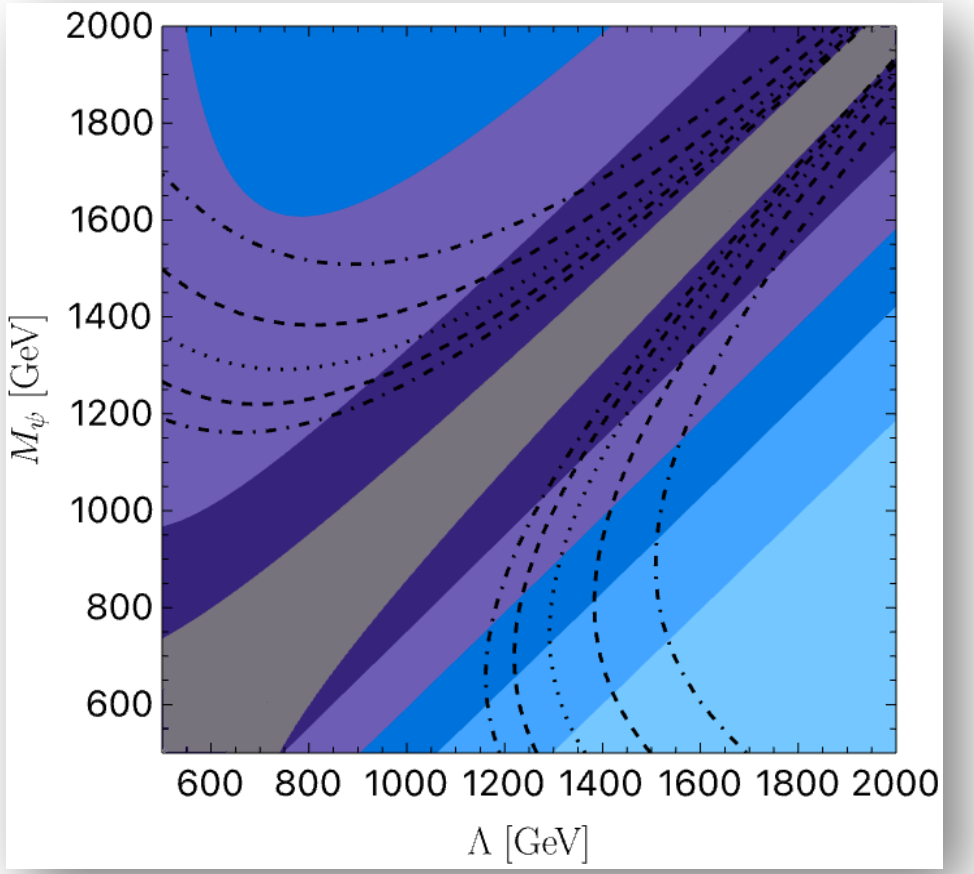
- Rotation to mass basis
- 1-loop diagram

After matching to EFT →

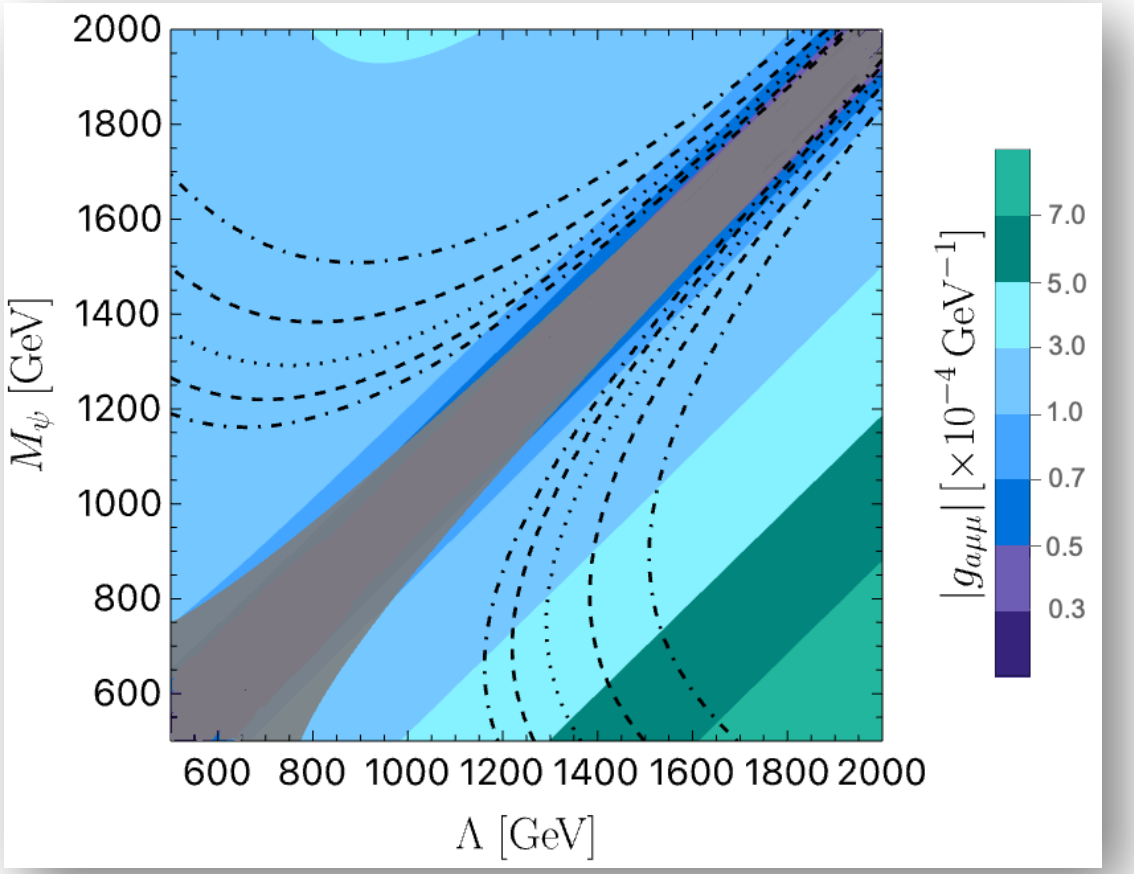
$$g_{a\mu\mu} = \frac{(\overline{\delta}_{x,1} + \overline{\delta}_{y,1})}{f_a} \times \left(\frac{Y_V}{Y_V + \left(\frac{M_\psi}{\Lambda}\right) Y_{V'}} \right)$$

It is also possible to get correct behaviour from symmetry arguments

Coupling to muons (model A)



$Y_V = 0.1$



$Y_V = 0.5$