Probing the Dark Axion Portal with Muon Anomalous Magnetic Moment

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2104.03276

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• Introduction

The new result on muon anomalous magnetic moment at Fermilab:

B. Abi et al. (Muon g - 2 Collaboration) Phys. Rev. Lett. 126, 141801 (2021)

$$a_\mu^{\text{exp}}(\text{FNAL}) = 116592040(54) \times 10^{-11}$$

$$a_\mu^{\text{exp}}(\text{BNL}) = 116592080(63) \times 10^{-11}$$

G. W. Bennett et al. al. [Muon g-2] Phys. Rev. D 73 (2006), 072003

Combined value:

$$a_\mu^{\text{exp}} = 116592061(41) \times 10^{-11}$$

• Introduction

SM prediction for muon anomalous magnetic moment:

Large uncertainty

$$a_\mu^{\rm SM} = a_\mu^{\rm QED} + a_\mu^{\rm EW} + a_\mu^{\rm HVP} + a_\mu^{\rm HLbL}$$

$116584718.931(104) \times 10^{-11}$

$153.6(1.0) \times 10^{-11}$

$6845(40) \times 10^{-11}$

$92(18) \times 10^{-11}$

$$a_\mu^{\rm SM} = 116591810(43) \times 10^{-11}$$

T. Aoyama et al , Phys. Rept. 887, 1- 166 (2020)

• Introduction

The difference between the experimental value and SM prediction:

$$\Delta a_\mu \equiv a_\mu^{\rm exp} - a_\mu^{\rm SM} = 251(59) \times 10^{-11}$$

4.2σ **discrepancy between experiment and SM prediction!**

New Physics??

lepton flavor violation; Z'; neutral scalars; ALP; leptoquarks;

supersymmetry; dark photon; dark matter portals

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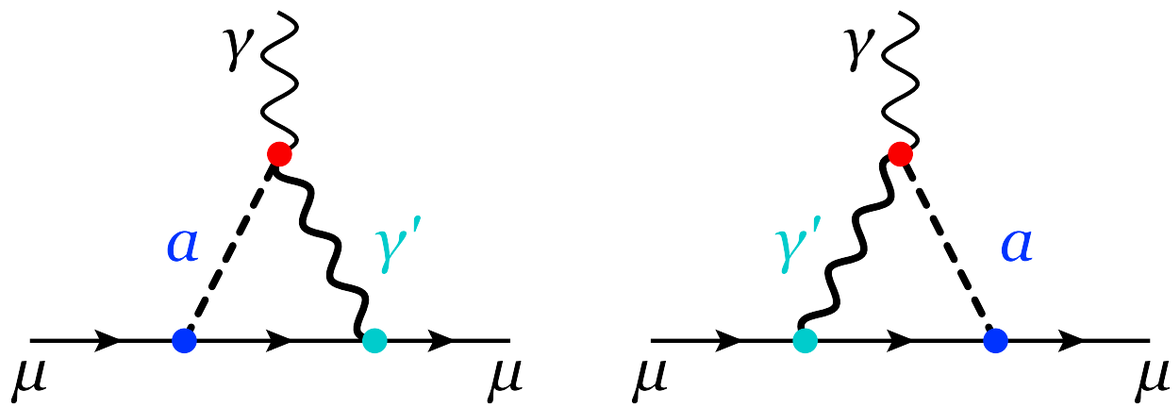
+ more in old age

• Dark axion portal to explain the Δa_μ

Consider TeV scale heavy NP: $C_{a\gamma\gamma'} \sim \Lambda_{\rm NP} \sim 1{\rm TeV}^{-1}$

$$\mathscr{L} \ni \frac{1}{2} C_{a\gamma\gamma'} a F^{\mu\nu} \widetilde{X}_{\mu\nu} \longrightarrow \text{dark photon } \gamma'$$

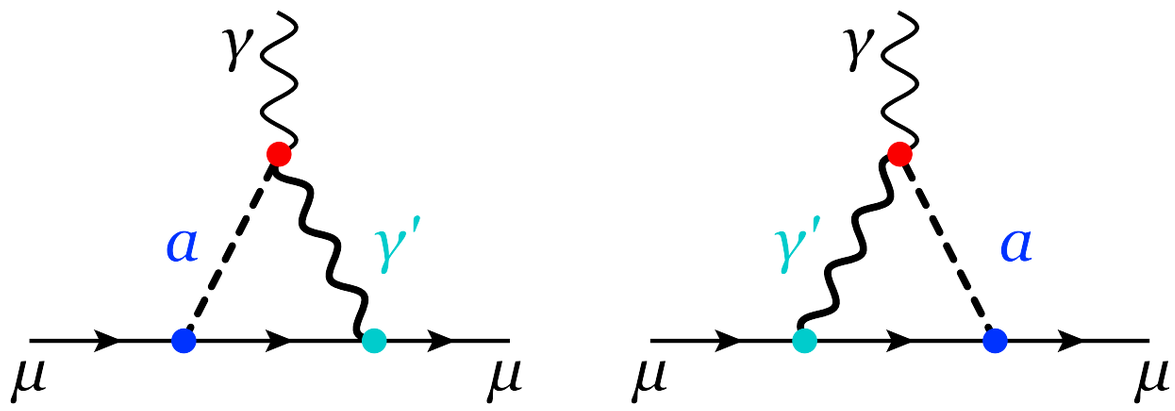
ALP: axion-like particle **photon** γ



$$\mathscr{L} \ni y_a^\mu a \bar{\mu} \left(i\gamma_5\right) \mu - \epsilon e \bar{\mu} \gamma^\nu \mu X_\nu$$

• The Dark Axion Portal Contribution

$$\mathscr{L}_{\gamma\mu\mu} \equiv \Delta a_\mu \frac{e}{4m_\mu} \bar{\mu}\sigma_{\mu\nu}\mu F^{\mu\nu}$$



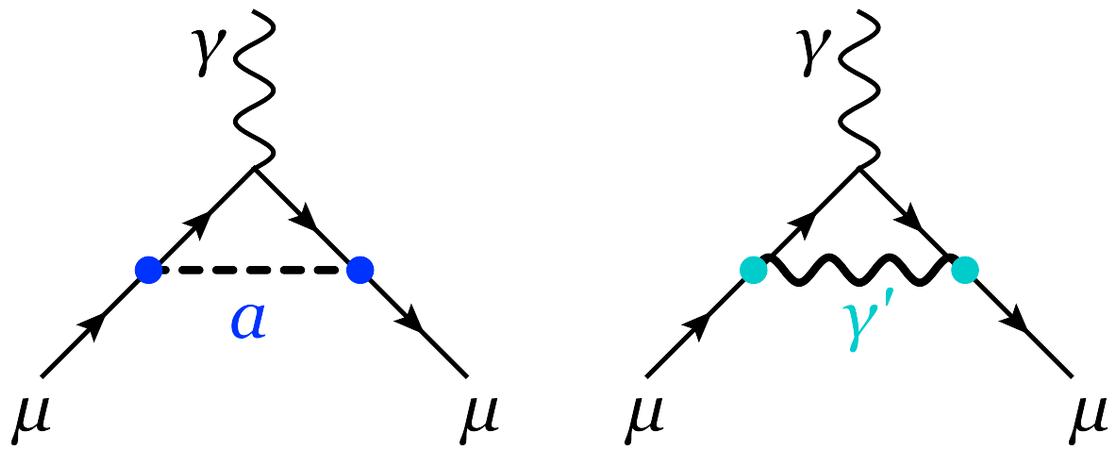
$$a_\mu = \frac{m_\mu}{4\pi^2}\epsilon y_a^\mu C_{a\gamma\gamma'} G$$

→ **linear in m_μ**

$$G \equiv \int_0^1 dx \left[(1-x)\left(\ln \frac{\Lambda^2}{(1-x)m_a^2 + x^2 m_\mu^2} - \frac{1}{2} \right) - \frac{(1-x)m_{\gamma'}^2 + 2x^2 m_\mu^2}{m_a^2 - m_{\gamma'}^2} \ln \frac{(1-x)m_a^2 + x^2 m_\mu^2}{(1-x)m_{\gamma'}^2 + x^2 m_\mu^2} \right]$$

cut-off scale to regularize UV divergence: same order as the UV scale $\Lambda = 1$ TeV

• The Individual Contribution of a or γ'



$$a_\mu^a = \frac{(y_p^\mu)^2}{4\pi^2}\frac{m_\mu^2}{m_a^2}F_a\left(\frac{m_\mu}{m_a}\right)$$

$$F_a(\eta) \equiv -\frac{1}{2}\int_0^1 \mathrm{d}x \frac{x^3}{(1-x)\left(1-\eta^2 x\right)+\eta^2 x}$$

Always negative

$$a_\mu^{\gamma'} = \frac{\epsilon^2 e^2}{4\pi^2}\frac{m_\mu^2}{m_{\gamma'}^2}F_{\gamma'}\left(\frac{m_\mu}{m_{\gamma'}}\right)$$

$$F_{\gamma'}(\eta) \equiv \frac{1}{2}\int_0^1 \mathrm{d}x \frac{2x^2(1-x)}{(1-x)\left(1-\eta^2 x\right)+\eta^2 x}$$

- **No UV divergence.**
- **Each single contribution does not work!**

• Setup for searching for parameter space

$$\Delta a_\mu \equiv a_\mu^{\rm exp} - a_\mu^{\rm SM} = 251(59) \times 10^{-11}$$

$$\chi^2 \equiv \left(\frac{\Delta a_\mu^{\rm cen.} - \Delta a_\mu^{\rm NP}}{\sigma\left(\Delta a_\mu\right)} \right)^2 < 5.99 \quad @\ 95\,\%$$

- **Central value:** $\Delta a_\mu^{\rm cen.}$
- **Uncertainty:** $\sigma\left(\Delta a_\mu\right)$
- $C_{a\gamma\gamma'} = 3{\rm TeV}^{-1}$ **to satisfy the current bound from BaBar** $e^+e^- \to \gamma' a$

P. deNiverville, H. S. Lee and M. S. Seo Phys. Rev. D 98, no.11, 115011 (2018)

• Comparison

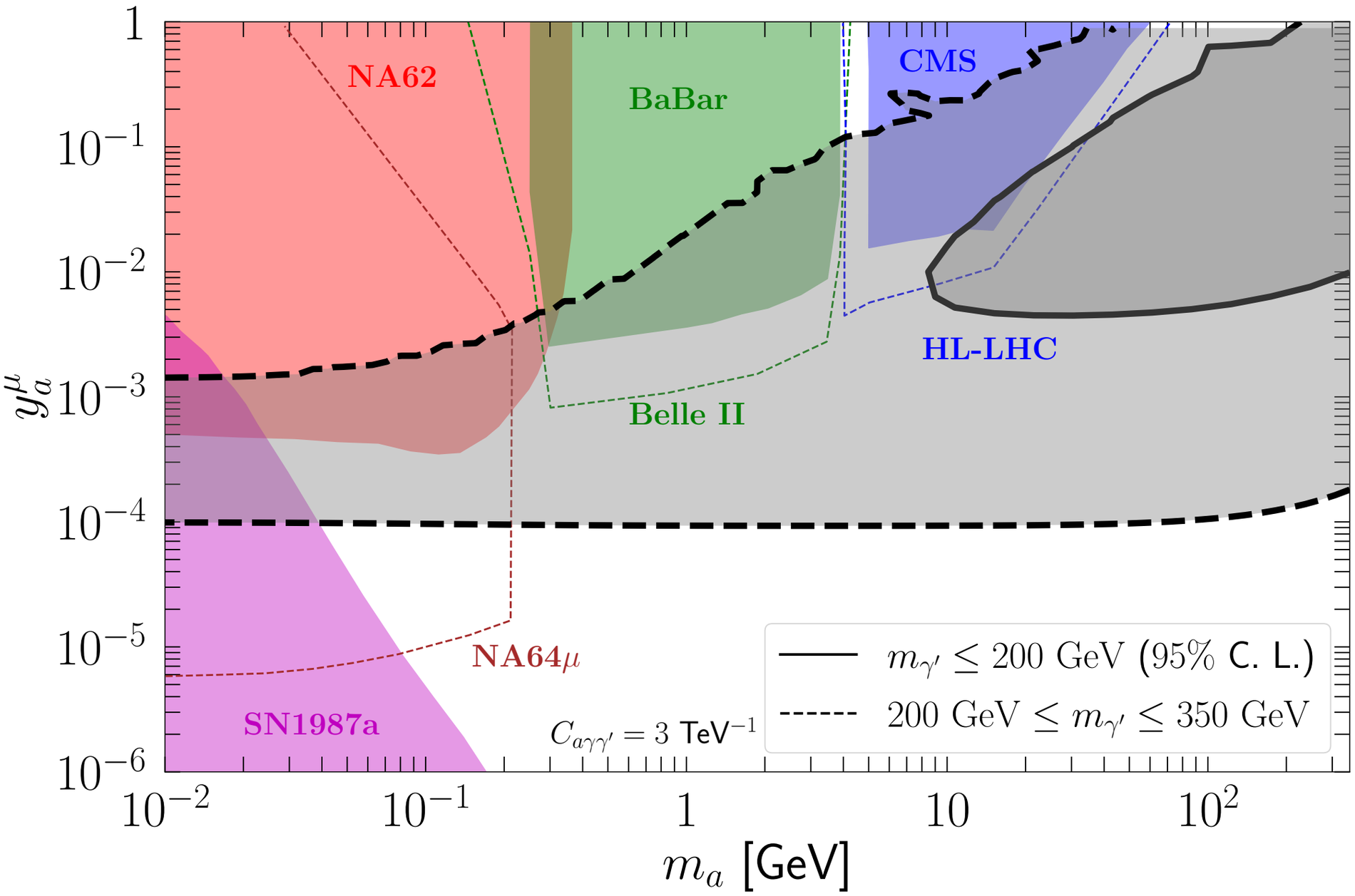
$$\frac{a_\mu}{a_\mu^a} \sim \frac{\epsilon}{y_a^\mu}\frac{m_a^2 C_{a\gamma\gamma'}}{m_\mu} \sim \frac{\epsilon}{10^{-3}}\frac{0.1}{y_a^\mu}\left(\frac{m_a}{100\text{GeV}}\right)^2$$

$$\frac{a_\mu}{a_\mu^{\gamma'}} \sim \frac{y_a^\mu}{\epsilon e^2}\frac{m_{\gamma'}^2 C_{a\gamma\gamma'}}{m_\mu} \sim 10^5\frac{10^{-3}}{\epsilon}\frac{y_a^\mu}{0.1}\left(\frac{m_{\gamma'}}{100\text{GeV}}\right)^2$$

If $a_\mu \gg a_\mu^a, a_\mu^{\gamma'} \Rightarrow m_a \gg \sqrt{y_a^\mu/\epsilon}\,10\text{GeV},\ \ m_{\gamma'} \gg \sqrt{\epsilon/y_a^\mu}\sqrt{10}\text{GeV}$

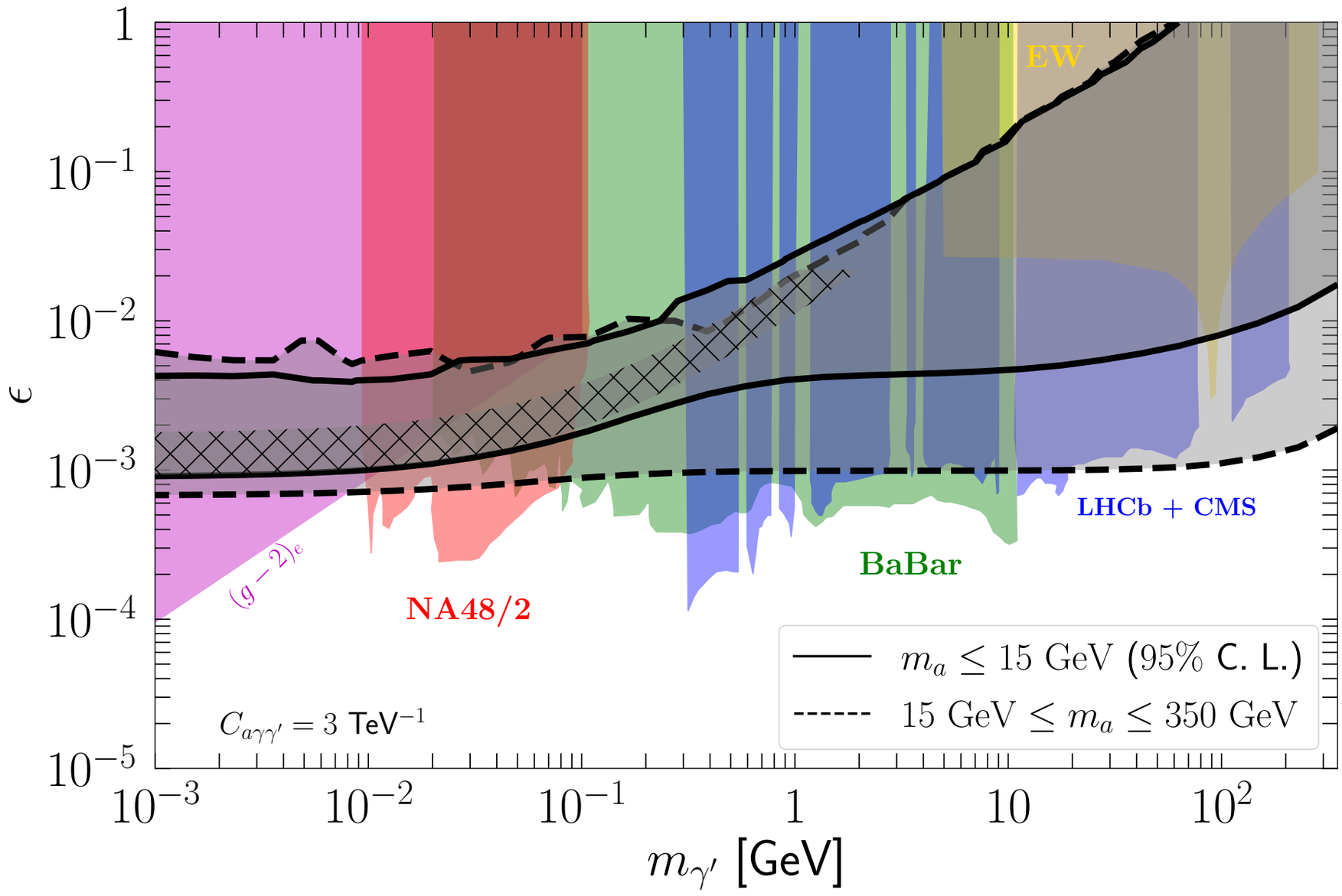
For comparable couplings of ϵ **and** $y_a^\mu \Rightarrow$ **GeV scale** a **and** γ'

• Parameter space: $m_a - y_a^\mu$ plane



- **NA62:** $K \to \mu\nu a$ Croon, G. Elor, R. K. Leane and S. D. McDermott. JHEP 01, 107 (2021)
- **SN1987a:** $\nu + n(p) \to \mu^-(\mu^+) + p(n) \to \mu + \gamma \to a + \mu, \mu + X \to a + \mu + X$
- **BaBar:** $e^+e^- \to \mu^+\mu^- a$ B. Batell, N. Lange, D. McKeen, M. Pospelov and A. Ritz,Phys. Rev. D 95, no.7, 075003(2017)
- **CMS: rare Z decay** J. P. Lees et al. [BaBar],Phys. Lett. B 792 (2019), 345- 368

• Parameter space: $m_{\gamma'} - \epsilon$ plane



- **Electron anomalous magnetic moment:** $(g-2)_e$ 0811.1030
- **NA48: dark photon from pion decay** 1504.00607
- **BaBar: resonant production of dark photon** 1406.2980
- **LHCb+CMS: dark photon production from mesons + Higgs** 1603.08926, 1910.06926 , 1912.04776
- **Hashed: muon** $(g-2)_\mu$ **from single dark photon**

• Dark photon to SM Z

$$\frac{1}{2}C_{a\gamma Z}aF_{\mu\nu}\tilde{Z}^{\mu\nu}$$

- $e\epsilon \rightarrow g_V = \frac{g}{c_W}\left(\frac{1}{4} - s_W^2\right) \approx 4.5 \times 10^{-2} e$;

- **Two parameters m_Z and g_V are fixed;**

- $C_{a\gamma\gamma'} \rightarrow C_{a\gamma Z} \leq 0.03\ \mathrm{TeV}^{-1}$ **from** $Z \rightarrow \gamma a$;

K. Cheung, T. W. Kephart, W. Y. Keung and T. C. Yuan, Phys. Lett. B 662 (2008), 436-440

- **The contribution is negligibly small.**

• Summary

- the Fermilab Muon g-2 experiment enhances the Δa_μ discrepancy with SM prediction from 3.7 σ to 4.2 σ;

- The dark axion portal can surprisingly save the ALP and dark photon for explaining the muon anomalous magnetic moment;

- The observed muon anomalous magnetic moment provides a robust probe of the dark axion portal scenario.

Thanks for your attention!