Theoretical Interpretations of the Muon g-2 discrepancy

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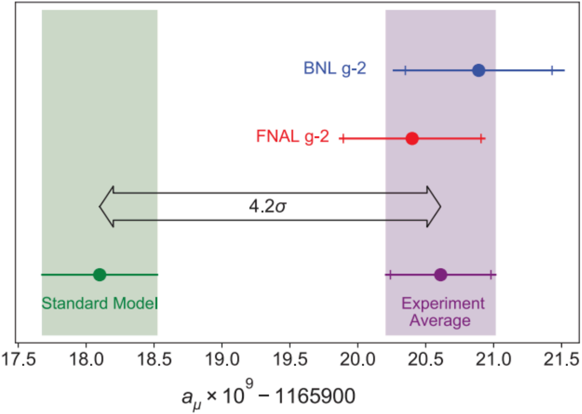
Outline

What is Muon g-2 discrepancy and experiment implication?

Our interpretations on Flavor Specific Scalar Mediator

Something New



Dark Sector: existence of mediator

Motivation

Why do we need new mediator besides SM?

- Light dark matter (sub-GeV)
  Null results of WIMP direct detection $\rightarrow$ There is huge room for light dark matter detection $\rightarrow$ Can we go lower in DM mass?$\rightarrow$ Correct relic density requires light mediator
- Muon g-2
  $$\Delta a_\mu = a_\mu^{\mathrm{exp}} - a_\mu^{\mathrm{th}} = (2.51 \pm 0.59) \times 10^{-9}$$
- Proton radius
  Measuring R_p using electrons: $0.88\mathrm{fm}$, using muons: $0.84\mathrm{fm}$

Classification of Mediators

EFT: coupling Dark Sector to SM via portals according to spin

- Higgs-singlet scalar interactions (Higgs portal)

$$H^+ H \left(\lambda S^2 + AS\right)$$

- Kinetic mixing with additional U(1) group (Dark photon portal)

$$\epsilon B^{\mu\nu} F'_{\mu\nu}$$

- Neutrino Yukawa coupling (Neutrino portal)

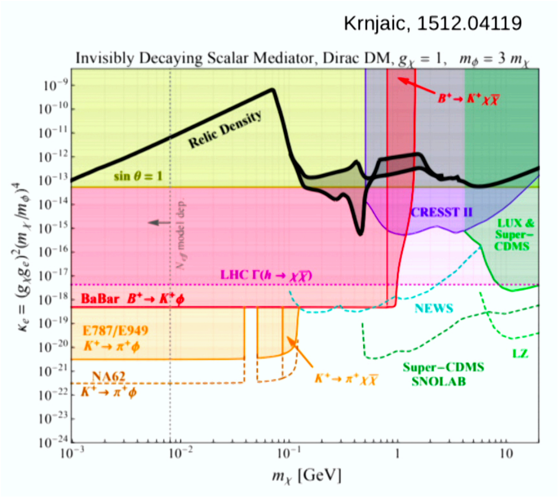
$$y_\nu L H N$$

They are renormalizable portals

Proton radius favors scalar mediator!

Dying of Higgs Portal

Rare meson decay constrains the model too much!



Going Beyond Fermion University and Renormalizablity

Adding a flavor specific scalar with dimension-5 operator

$$-\mathcal{L}_{\text{d}=5} = \frac{C_u^{ij}}{M}\phi H^c \bar{Q}_L^i u_R^j + \frac{C_d^{ij}}{M}\phi H \bar{Q}_L^i d_R^j + \frac{C_e^{ij}}{M}\phi H E_L^i e_R^j + h.c.$$

- Operators with derivative are removed by field redefinition
- Neutrino operator is suppressed by dimension-6 operator $\phi(HL)^2$
- Coefficients $C_{u,d,e}^{ij}$ is generic 3×3 matrix in flavor space $\rightarrow$ FCNC!

Need to deal with the Wilson Coefficients

Introduce Flavor Symmetries

Flavor Symmetries → Spurion Analysis

SM without Yukawas has flavor symmetry

$$U(3)_Q \times U(3)_U \times U(3)_D \times U(3)_L \times U(3)_E$$

Minimal Flavor Violation

Yukawa couplings are only source of flavor symmetry breaking

- MFV: $C_{u,d,e} \sim Y_{u,d,e}$
  Everything is Yukawa.
- Next-to-MFV: new physics only couples to third generation
  Respect $U(2)^5$ Somewhat boiling from experimental view
- Our approach-Generalization: coupling to a single fermion but not third generation

Flavor Specific Scalar Mediator

Forget Yukawas and assume our flavor symmetry breaking pattern

$$U(3)_U \to U(3)_U$$
$$U(3)_Q \times U(3)_D \to U(1)_d \times U(2)_L^{s,b} \times U(2)_R^{s,b}$$
$$U(3)_L \times U(3)_E \to U(1)_\mu \times U(2)_L^{e,\tau} \times U(2)_R^{e,\tau}$$

Only C_d^{11} and C_e^{22} are non-vanishing

$$-\mathcal{L}_{\text{Portal}} = g_d \phi \bar{d}_L d_R + g_\mu \phi \bar{\mu}_L \mu_R + \text{ h.c.}$$

Fitting the Excess

- Muon g-2

$$\Delta a_\mu = \frac{g_\mu^2}{8\pi^2}\int_0^1 dz \frac{(1-z)^2(1+z)}{(1-z)^2 + (m_\phi/m_\mu)^2 z}$$

- Lamb shift for proton radius

$$\delta E^{\mu\mathrm{H}}_{\mathrm{Lamb}} = -0.307(56)\mathrm{meV} = -\frac{g_\mu}{8\pi a_{\ell\mathrm{N}}}\left[Z g_p + (A-Z) g_n\right] f\left(a_{\ell\mathrm{N}} m_\phi\right)$$

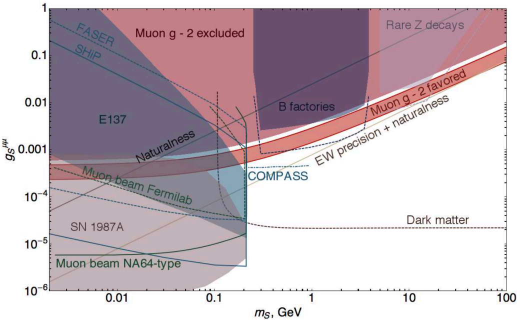
Overlap Point

1.8MeV mediator, $g_\mu \sim 5\times 10^{-4}, g_d \sim 8\times 10^{-5}$ solves both

Severly Constrained$\rightarrow$ Almost ruled out

Two Dangerous Constraints From Photon Channel: E137 and SN 1987A

See 1712.10022



- E137 can be removed by allowing ϕ decaying into sub-MeV dark matter pair $m_\phi > 2m_\chi$
- g_d lowers the coupling g_μ

Sub-MeV DM Problem

Sub-MeV DM only annihilates into photon, leading to overproduction

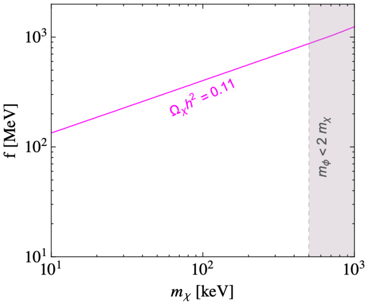
$$\chi\chi \to \phi \to dd, \quad \text{Only valid at} \quad m_\chi > \Lambda_{\rm QCD}$$

Sub-MeV DM generates unacceptable $\Delta N_{\rm eff}$

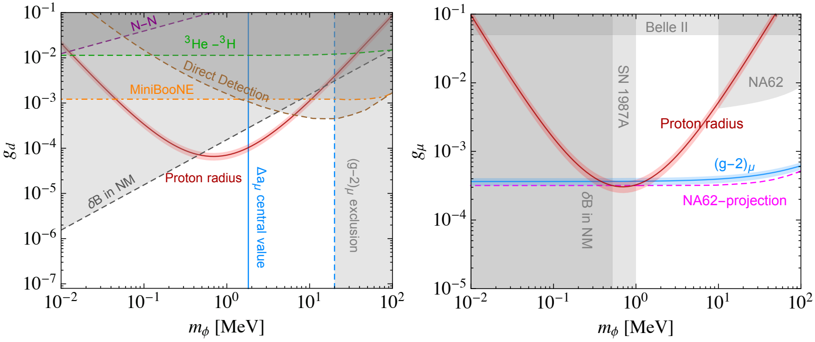
$$\rho_{\rm rad} \equiv \rho_\gamma \left[1 + (7/8)(4/11)^{4/3} N_{\rm eff}\right]$$

Delayed equilibrium between DM and neutrino can remove $\Delta N_{\rm eff}$ and reduce relic density

$$-\mathcal{L}_{\rm Neutrino} = y_v LNH + \frac{1}{2} y_N \Phi N^2 + \frac{1}{2} \lambda_\chi \Phi \chi^2$$



Results



Two interesting constraints:

- Direct Detection limit is obtained by calculation cosmic-ray boosted dark matter with mediator ϕ
- SN 1987A is the direct coupling for g_μ rather photon channel

Future Direction

Do NA64_μ and DD help?