Anomalous $(g-2)$ of μ and $h \to \mu\mu$ coupling in a sequential $U(1)$ gauge model with dark matter

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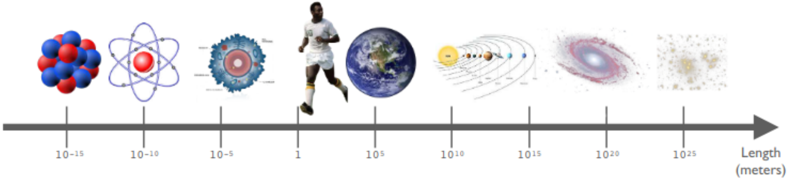
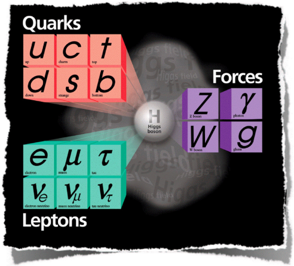
Based on 2109.05417 (with R. Adhikari, I.A. Bhat, D. Borah, E. Ma)

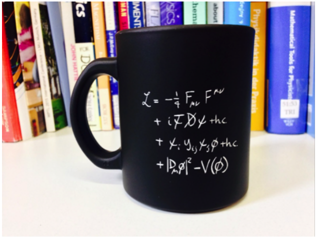
Outline

- Introduction
- Motivation of our work
- A minimal framework
- Results
- Conclusion

A Magnificent Unified Description







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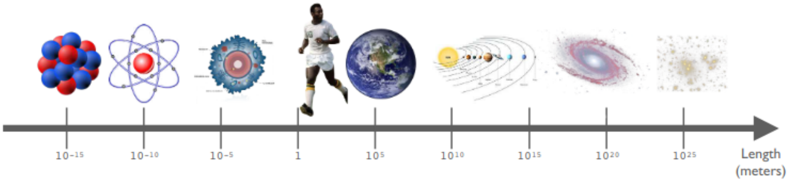

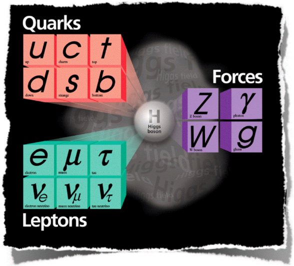

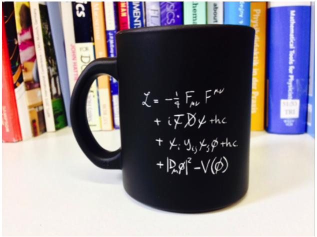

Can we declare victory?

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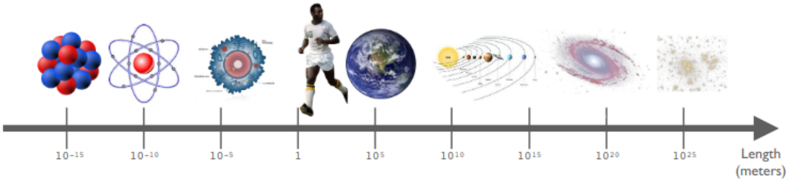

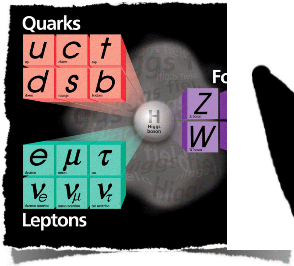

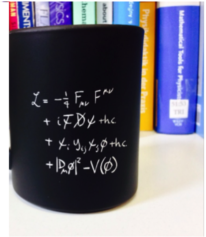

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- Electrically neutral
- Stable over the age of the universe
- Massive
- Relic abundance ($\Omega h^2 = 0.12$)

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Looking for Dark Matter

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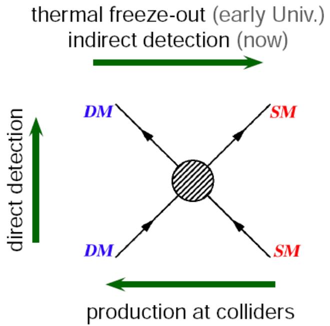

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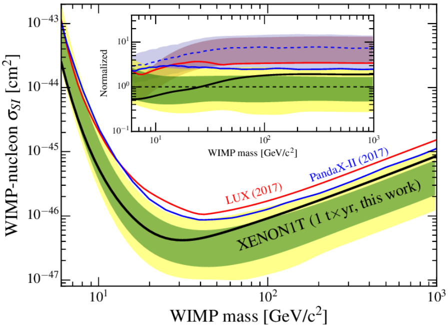
No positive signal in DD experiments.



- Alternatives - Multi-component DM, FIMP, SIMP etc

Motivations

$\mathrm{SU(3)_C \times SU(2)_L \times U(1)_Y}$ ➕ $\mathrm{U(1)_X}$ ⟶ **Anomalous**

- The anomaly free conditions can be written as: $\sum_{i=1}^{3} 3n_i + n_i'$. Ma et al(2017)
- The well-known $B - L$ gauge symmetry can be obtained with the introduction of three singlet right-handed neutrinos with charge -1.
- However, instead of ν_R the anomaly can also be canceled with three lepton triplets Σ_R.

$$(u,d)_L \sim (3,2,1/6;n_1), \quad u_R \sim (3,1,2/3;n_2), \quad d_R \sim (3,1,-1/3;n_3),$$
$$(\nu,e)_L \sim (1,2,-1/2;n_4), \quad e_R \sim (1,1,-1;n_5), \quad \Sigma_R \sim (1,3,0;n_6).$$

$$n_2 = \frac{1}{4}(7n_1 - 3n_4), \quad n_3 = \frac{1}{4}(n_1 + 3n_4), \quad n_5 = \frac{1}{4}(-9n_1 + 5n_4), \quad n_6 = \frac{1}{4}(3n_1 + n_4),$$

Ma et al(2002)

Motivations

- The usual gauge symmetry has been studies with the same charges for each families. Ma et al (2002)
- However, very recently it has been shown that different charges for three different families can also be chosen. Ma et al (2021)

Important points to note

- The charges can be chosen in such a way that only the third generation of the fermions can interact with higgs via renormalisable couplings.
- The first two generations of charged fermions acquire masses only at radiative level.
- The same loop will be responsible for the generation of μ mass and $(g-2)_\mu$.
- The new fields introduced for radiative charged fermion masses can also serve as a stable dark matter (DM) candidate, if it is stable and neutral.

Radiative μ mass

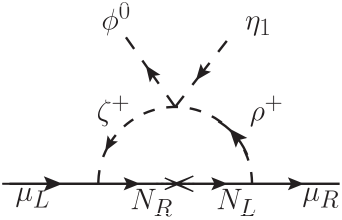
- The important interaction can be written as,

$$\mathcal{L} \supset -y_\zeta \bar{L_\mu} \tilde{\zeta} N_R - y_\rho \bar{N}_L \rho \mu_R - \lambda \Phi \zeta \eta_1^\dagger \rho^\dagger$$

- The one loop muon mass can be estimated as,

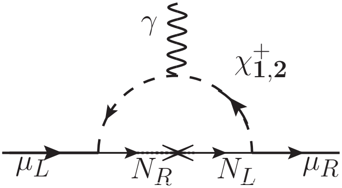
$$m_\mu = \frac{Y_\zeta Y_\rho}{16\pi^2} \frac{\lambda v u_1}{2} \frac{M_N}{M_{\chi_1^+} M_{\chi_2^+}} I(x_1, x_2)$$

where $x_1 = \frac{M^2_{\chi_1^+}}{M_N^2}$ and $x_2 = \frac{M^2_{\chi_2^+}}{M_N^2}$



Anomalous magnetic moment of μ

- The same loop can also lead to the anomalous magnetic moment of muon.
- The contribution from this loop is enhanced.



The corresponding contribution to muon $(g-2)$ will be

$$\Delta a_\mu = \frac{m_\mu^2}{M_N^2}\left(\frac{x_1 \ln x_1}{1-x_1} - \frac{x_2 \ln x_2}{1-x_2}\right)^{-1}\left[\frac{3x_1-1}{(1-x_1)^2} - \frac{3x_2-1}{(1-x_2)^2} + \frac{2x_1^2 \ln x_1}{(1-x_1)^3} - \frac{2x_2^2 \ln x_2}{(1-x_2)^3} + 2\left(\frac{1}{1-x_1} - \frac{1}{1-x_2} + \frac{x_1 \ln x_1}{(1-x_1)^2} - \frac{x_2 \ln x_2}{(1-x_2)^2}\right)\right]$$

$h \to \mu^+\mu^-$ and $h \to \gamma\gamma$ decay

- The Higgs to $\overline{\mu}\mu$ coupling is predicted to be different than the SM results

$$y_\mu^{SM} = \frac{m_\mu}{246\ GeV}$$

- The effective coupling can be written as

$$Y_\mu^{\rm eff} = \frac{\sqrt{2} m_\mu}{v}\left[\cos^2(2\theta_{\rm ch}) + \frac{1}{2}\sin^2(2\theta_{\rm ch})\frac{\sqrt{x_1 x_2}}{I(x_1, x_2)}\left(\frac{I(x_1)}{x_1} + \frac{I(x_2)}{x_2}\right)\right]$$

- A recent observation reports

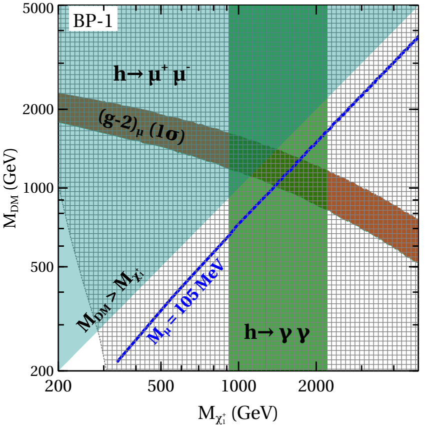
$$0.8 \times 10^{-4} < BR(h \to \overline{\mu}\mu) < 4.5 \times 10^{-4}$$

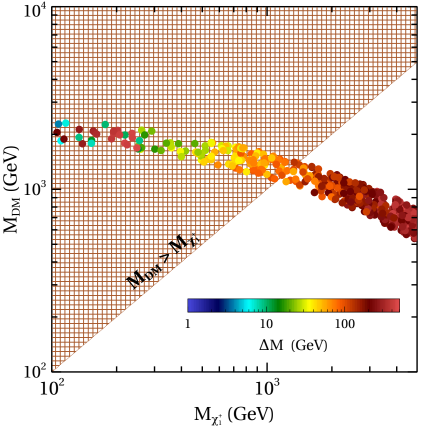
- The same parameters can also alter the SM prediction for Higgs to diphoton decay and the new contribution should satisfy,

$$\frac{\mathrm{BR}(h \to \gamma\gamma)_{\rm New}}{\mathrm{BR}(h \to \gamma\gamma)_{\rm expt}} = 0.0291 \ \text{ to } \ 0.1735$$

Results

- One important point to note here is that we require large yukawa to satisfy all possible bounds.





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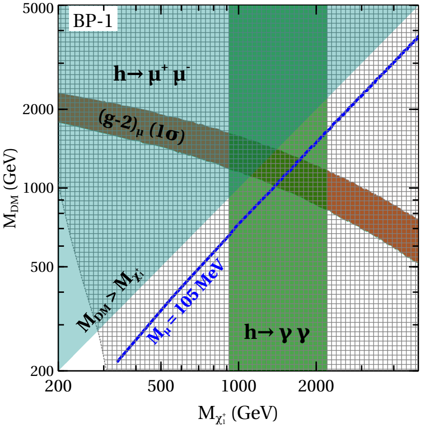
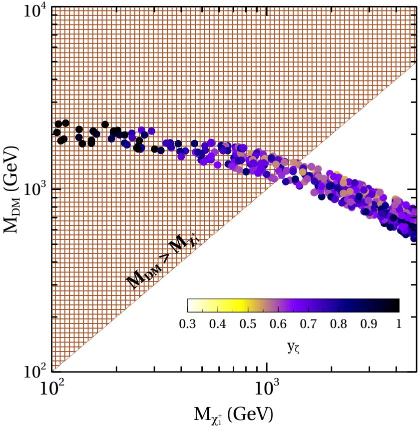
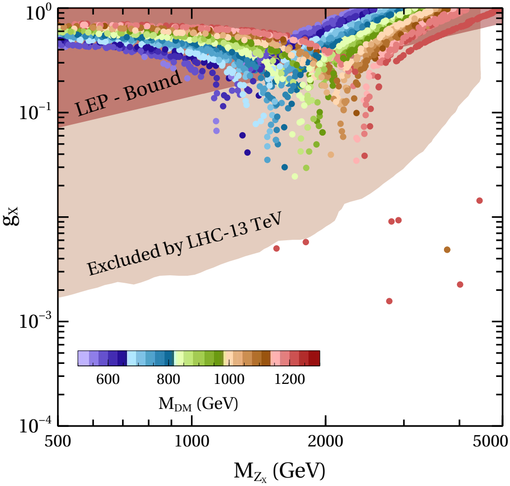




Relic density of dark matter

- The neutral singlet vector like fermion $N_{L,R}$ is the dark matter candidate in this model.



Conclusions

- We have studied an Abelian gauge extension of the standard model with radiative muon mass leading to anomalous magnetic moment as well as anomalous Higgs coupling of muon having very interesting consequences at experiments.
- The model also predicts a stable fermion singlet dark matter candidate which goes inside radiative muon mass loop in scotogenic fashion.
- Taking into account of all relevant constraints related to muon mass along with its $(g-2)$, Higgs coupling to muons, Higgs to diphoton decay, direct search bounds from colliders as well as dark matter phenomenology lead to a tiny region of parameter space that can be probed at future experiments.


Thank you!

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