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Correlating Muon $g-2$ Anomaly with Neutrino Magnetic Moments

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We show that the models that induce neutrino magnetic moments, while maintaining their small masses naturally, also predict observable shifts in the muon anomalous magnetic moment. This shift is of the right magnitude to be consistent with the Brookhaven measurement as well as the recent Fermilab measurement of the muon $g-2$. Thus, it provides the most minimal and standalone framework to solve the decades-old neutrino mass-magnetic moment puzzle and which simultaneously addresses three shortcomings of the SM (a) neutrino mass generation, (b) large neutrino magnetic moment (in order to address the Xenon1T anomaly) and (c) muon $g-2$ anomaly. This is pointing out the direct correlation between the magnetic moment of SM charged lepton and neutral lepton (neutrino) by showing that the measurement of muon $g-2$ by the Fermilab experiment can be an in-direct and novel test of the neutrino magnetic-moment hypothesis, which can be as sensitive as other ongoing-neutrino/dark matter experiments. Such a correlation between muon $g-2$ and the neutrino magnetic moment is generic in models employing leptonic family symmetry to explain a naturally large neutrino magnetic moment. This talk is based on results obtained with K.S. Babu, Manfred Lindner, and Vishnu P.K. and presented in hep-ph 2007.04291 [1] and 2104.03291 [2].

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There has been considerable interest in understanding the long-standing discrepancy between the measured and predicted values of the anomalous magnetic moment of the muon, a_μ. The Brookhaven Muon g-2 collaboration has measured it to be $a_\mu(\text{BNL}) = 116592089(63) \times 10^{-11}$ two decades ago [3], while theoretical predictions find it to be $a_\mu(\text{theory}) = 116591810(43) \times 10^{-11}$ [4]. Taken at face value the difference, $\Delta a_\mu = a_\mu(\text{experiment}) - a_\mu(\text{theory}) \simeq 279 \times 10^{-11}$, is a 3.7 sigma discrepancy, which may indicate new physics lurking around or below the TeV scale. Very recently the Fermilab Muon g-2 collaboration [5] has announced their findings, which measures it to be $a_\mu(\text{FNAL}) = 116592040(54) \times 10^{-11}$ which confirms the Brookhaven measurement and increases the significance of the discrepancy to the level of 4.2 sigma. These results make the motivations for new physics explanation more compelling.

The purpose of this note is to draw a connection between new physics contributions to a_μ and a possible neutrino transition magnetic moment $\mu_{\nu_\mu \nu_e}$. A sizable neutrino magnetic moment has been suggested as a possible explanation for the excess in electron recoil events observed in the $(1-7)$ keV recoil energy range by the XENON1T collaboration recently [6]. The neutrino magnetic moment needed to explain this excess lies in the range of $(1.6 - 2.4) \times 10^{-11} \mu_B$, where μ_B stands for the electron Bohr magneton [1]. Such a value would require new physics to exist around the TeV scale. As we shall show in this paper, models that induce neutrino magnetic moments, while maintaining their small masses naturally, also predict observable shifts in the muon anomalous magnetic moment. We focus on a specific class of models based on an $SU(2)_H$ horizontal symmetry (or family symmetry) acting on the electron and muon families that naturally leads to a large neutrino magnetic moment [1]. We find that within this class of models, an explanation of the XENON1T excess will necessarily lead to *a positive contribution* to Δa_μ, which lies neatly within the Brookhaven and the recent Fermilab measurements of a_μ [5]. This class of models is thus in accordance with Occam's razor, explaining both anomalies in terms of the same new physics.We have also outlined various other experimental tests of these models at colliders. The entire parameter space of the model can be explored at the HL-LHC through the pair production of neutral scalars and their subsequent decays into $e\tau$ and $\mu\tau$ final states.

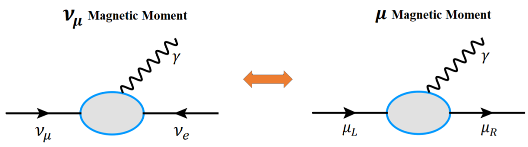

Figure 1: New physics affecting muon anomalous magnetic moment as well as ν_μ-magnetic moment.

Fig. 1 shows the connection between Δa_μ and $\mu_{\nu_\mu \nu_e}$ in a generic model. Fig. 2 has the explicit diagrams in the $SU(2)_H$ symmetric models. We first focus on the new contributions to the muon anomalous magnetic moment within our framework. Both the neutral scalars and charged scalars present in the model contribute to Δa_μ via one-loop diagrams shown in Fig. 2. Since chirality flip occurs on the external legs in these diagrams, the loop corrections mediated by the neutral scalars ϕ_1^0 and ϕ_2^0 contribute positively to a_μ, whereas the corrections from the charged scalars result in negative a_μ.

We now turn to the transition magnetic moment of the neutrino in our framework and show its correlation with Δa_μ. The diagrams generating sizeable $\mu_{\nu_\mu \nu_e}$ are shown in Fig. 2, bottom panel.

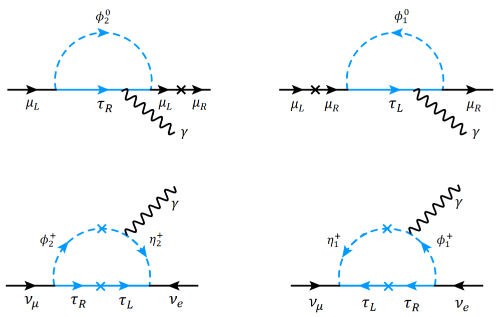

Figure 2: The dominant contributions to Δa_μ (top) and neutrino magnetic moment (bottom) are shown. For the neutrino magnetic moment, the outgoing photon can be emitted also from the τ lepton line. There are other diagrams, which are subleading.

Owing to the $SU(2)_H$ symmetry of the model, the two diagrams add in their contributions to the magnetic moment, while they subtract in their contributions to neutrino mass when the photon line is removed from these diagrams (for details, see Ref. [1]). The resulting neutrino magnetic moment is given by [1]

$$\mu_{\nu_\mu \nu_e} = \frac{f f'}{8\pi^2} m_\tau \sin 2\alpha \left[\frac{1}{m_{h^+}^2} \left\{ \ln \frac{m_{h^+}^2}{m_\tau^2} - 1 \right\} - \frac{1}{m_{H^+}^2} \left\{ \ln \frac{m_{H^+}^2}{m_\tau^2} - 1 \right\} \right] . \tag{1}$$

To see their correlation quantitatively, we have to take into account the various constraints that exist on these parameters, which we now address.

In Fig. 3 we have shown a direct correlation between the muon anomalous magnetic moment and neutrino magnetic moment within our framework. As noted before, the dominant contribution to Δa_μ solely depends on the Yukawa coupling f' and the neutral scalar mass m_{ϕ^0}. The transition magnetic moment of the neutrino $\mu_{\nu_\mu \nu_e}$ depends on the same Yukawa coupling f' as well as the charged scalar masses. The measurement of the $e^+e^- \to \tau^+\tau^-$ process at the LEP experiment imposes a strong limit on the Yukawa coupling f' as a function of the neutral scalar mass m_{ϕ_0}. Therefore, in Fig. 3, we vary the Yukawa coupling f' in such a way that the parameters are consistent with these constraints. An optimal scenario is realized when the neutral scalar is light, with its mass not lower than 45 GeV so as to be consistent with Z decay constraint. The mass splitting between the lightest charged scalar and neutral scalar is set to be 50 GeV in order to satisfy the charged Higgs mass limit of ~95 GeV (for detail see Ref. [7]) from collider searches. As for the charged scalar masses which have a strong impact on the neutrino magnetic moment, but little effect on the muon $g-2$, we note that these masses cannot be arbitrary, as the mass splittings between the charged and neutral scalars are tightly bounded from the electroweak precision data [7–9]. Therefore, it follows that there is no extra room to control the strength and the sign of the muon $g-2$ in our setup. The parameter space which predicts large neutrino magnetic moment leads to *a positive* contribution to muon $g-2$. Thus, the measurement of muon $g-2$ by the Fermilab experiment can be an indirect and novel test of the neutrino magnetic moment hypothesis, which can be as sensitive as other ongoing neutrino/dark matter experiments.

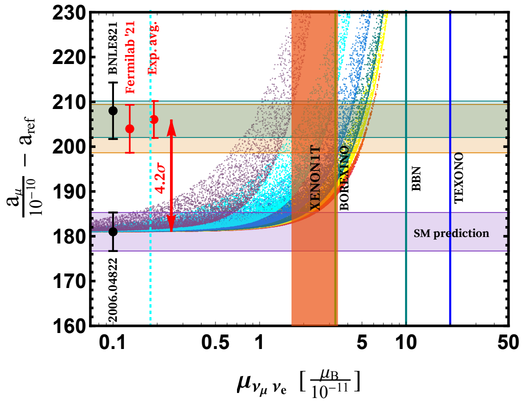

Figure 3: Theoretical predictions and experimental measurements of the muon anomalous magnetic moment and the neutrino transition magnetic moment. Purple, cyan, light blue, blue, green, yellow, orange and red scattered points depict the correlated predictions for the muon magnetic moment (a_μ) and neutrino magnetic moment ($\mu_{\nu_\mu \nu_e}$) in our framework for different ranges of mass splittings between the charged scalars: $m_{H^+} - m_{h^+} = 20, 50, 100, 200, 300, 500, 800$ and 1000 GeV. The lower black dotted point with error bar indicates the updated SM prediction [4] for a_μ. The upper dotted data points with error bars represent different experimental measurements: BNLE821 [3], Fermilab [5], and the the combined experimental average of the BNL [3] and Fermilab [5] results. These evaluations and measurements of a_μ are independent of neutrino magnetic moment values. The current uncertainty on the measurement of a_μ at the Fermilab [5] is given by the light brown band at 1σ level. The purple band represents the SM prediction from Ref. [4] with 1σ value and the light green band indicates the combined experimental average of the BNL [3] and Fermilab [5] results at 1σ level. Here we choose the reference value $a_{ref} = 11659000$. The orange band labelled with XENON1T denotes the preferred range $\mu_{\nu_e \nu_\mu} \in (1.65 - 3.42) \times 10^{-11} \mu_B$ to explain the electron recoil excess at 90% C.L [6]. The vertical lines indicate the limits on neutrino magnetic moment from various measurements: blue solid line from TEXONO, dark green solid line from BBN, light green solid line from BOREXINO, and cyan dashed line from globular clusters. The astrophysical limits on neutrino magnetic moment shown by the dashed cyan line can be evaded by utilizing a neutrino trapping mechanism [1].

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