Inelastic Dark Matter Interpretation of XENON1T Excess with $(g-2)_\mu$ and Light Neutrino Mass

Based on 2007.10754 (D. Borah, S. Mahapatra, DN, N. Sahu)

Dibyendu Nanda

Indian Institute Of Technology Guwahati

ANOMALIES 2020
International Conference (online)
IIT Hyderabad, Kandi, Telengana - 502285

Outline

- Motivation
- Gauged $\mathrm{L}_\mu - \mathrm{L}_\tau$ Model
- Neutrino Mass and $(\mathrm{g}-2)_\mu$
- Dark Matter
- XENON1T Excess
- Conclusion

Motivation

Standard model is the most successful theory in elementary particle physics. However

- Standard Model fails to to explain the existence of dark matter in our present day universe.
- Neutrinos are massless in the Standard Model, whereas in reality they are massive.
- XENON1T collaboration has recently reported an excess of electron recoil events near 1-3 keV energy.

Gauged $\mathrm{L}_\mu - \mathrm{L}_\tau$ Model

$$L_\mu = \begin{pmatrix} \nu_\mu \\ \mu_L \end{pmatrix} \sim (1, 2, -\frac{1}{2}, 1), \ \mu_R \sim (1, 1, -1, 1)$$

$$L_\tau = \begin{pmatrix} \nu_\tau \\ \tau_L \end{pmatrix} \sim (1, 2, -\frac{1}{2}, -1), \ \tau_R \sim (1, 1, -1, -1)$$

$$\chi_{L,R} \sim (1, 1, 0, \frac{1}{2}), \ \phi_1(\phi_2) \sim (1, 1, 0, 1(2))$$

$$N_e \sim (1, 1, 0, 0), \ N_\mu(N_\tau) \sim (1, 1, 0, 1(-1))$$

Neutrino Mass

- Neutrino mass will be generated through type-I seesaw mechanism.

$$m_\nu \simeq -M_D M_R^{-1} M_D^T$$

- The charged lepton mass matrix is diagonal in our model.
- The light neutrino mass matrix can be diagonalised by using the PMNS mixing matrix.

Muon $g-2$

- The magnetic moment of muon is given by

$$\vec{\mu_\mu} = g_\mu \left(\frac{q}{2m}\right) \vec{S}$$

- Any radiative correction, which couples the muon spin to the virtual fields, contributes to its magnetic moment and is given by

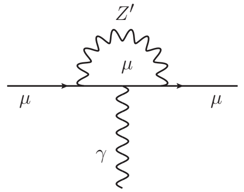
$$a_\mu = \frac{1}{2}(g_\mu - 2)$$

- This has been measured very precisely. At present the difference between the predicted and the measured value is given by T. Aoyama et al. 2006.04822

$$\Delta a_\mu = a_\mu^{\rm exp} - a_\mu^{\rm SM} = (27.9 \pm 22.8) \times 10^{-10}$$

- In our model, the contribution is given by

$$\Delta a_\mu = \frac{g_x^2}{8\pi^2} \frac{2m_\mu^2}{3M_{Z'}^2}$$



Dark Matter

- The DM field is identified as χ which has a bare mass as well as coupling to ϕ_1.

$$\mathrm{M}_\chi(\bar{\chi_\mathrm{L}}\chi_\mathrm{R} + \bar{\chi_\mathrm{R}}\chi_\mathrm{L}) + \frac{1}{2}(\mathrm{f}_1\overline{\chi_\mathrm{L}^c}\chi_\mathrm{L}\phi_1^* + \mathrm{f}_2\overline{\chi_\mathrm{R}^c}\chi_\mathrm{R}\phi_1^* + \mathrm{h.c.})$$

- While the bare mass term is of Dirac type, the coupling to ϕ_1 introduces a Majorana mass term after ϕ_1 acquires a non-zero VEV.
- That will split the Dirac fermion χ into two Majorana fermions χ_1 , χ_2.
- The relevent gauge interactions of χ_1 , χ_2 can be written as

$$(\mathrm{i}\frac{1}{2}\mathrm{g_x}\bar{\chi_2}\gamma^\mu\chi_1 Z'_\mu + \mathrm{h.c.}) + \frac{1}{4}\mathrm{g_x}\frac{\mathrm{m}_-}{\mathrm{M}_\chi}(\bar{\chi_2}\gamma^\mu\gamma^5\chi_2 - \bar{\chi_1}\gamma^\mu\gamma^5\chi_1)Z'_\mu$$

where $\mathrm{m}_- = \frac{(\mathrm{f}_1 - \mathrm{f}_2)\mathrm{v}_1}{2}$

- Singlet mixing with SM Higgs are assumed to be tiny so only the annihilations mediated by Z' gauge boson dominate.

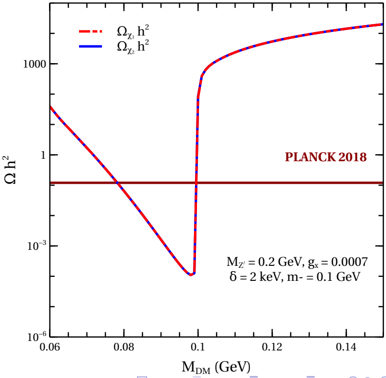
Relic Density of DM

- The independent parameters involved in the DM calculations are

$$\{g_x,\ M_{Z'},\ M_{DM},\ \delta,\ \text{and},\ m_-\}$$

- Throughout our analysis we have fixed δ at 2 keV.

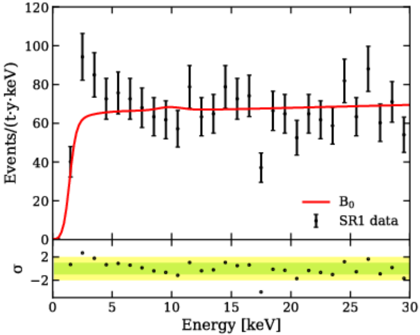
- We have solved these two coupled Boltzmann equations using micrOMEGAs.
- We find almost identical relic abundance of two DM candidates.
- Since δ is kept fixed at 2 keV, there can be decay modes like $\chi_2 \to \chi_1 \overline{\nu} \nu$.



XENON1T Excess

XENON1T collaboration has recently reported an excess of electron recoil events near 1-3 keV energy. 2006.09721

- Consistent with the solar axion model at 3.5σ significance.
- With neutrino magnetic moment signal at 3.2σ significance.
- Different dark matter (DM) interpretations of this excess have been proposed in several works.
  2006.10035, 2006.11243, 2006.10735, 2006.11938, 2006.12447, 2007.08205
- We consider the down-scattering of heavier DM component $\chi_2 e \to \chi_1 e$ as the process responsible for XENON1T excess.

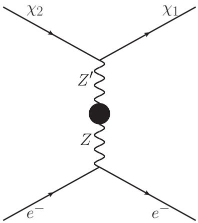


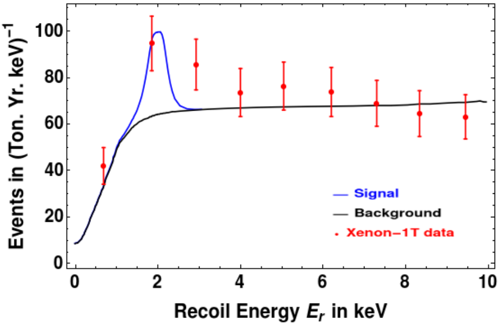
XENON1T Excess

Momentum transfer for this proces will depend on $\mathrm{v},\ \delta\,,\mathrm{E_r}\,,$ and, $\mathrm{M_{DM}}$

$$\sigma_{\mathrm{e}} = \frac{16\pi\,\alpha_{\mathrm{z}}\,\alpha_{\mathrm{x}}\,\epsilon^2\,\mathrm{m_e^2}}{\mathrm{M^4_{Z'}}}$$

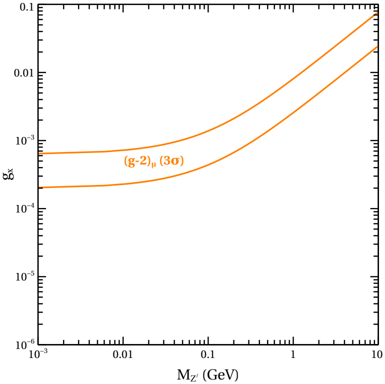
$$\mathrm{v} = 5\times10^{-3},\ \mathrm{g_x} = 7\times10^{-4},$$
$$\delta = 2\mathrm{keV},\ \mathrm{M_{Z'}} = 0.2\,\mathrm{GeV},\ \epsilon = 5\times10^{-3}$$





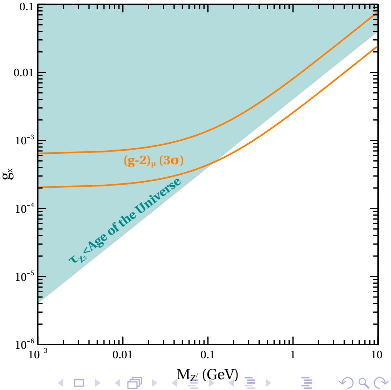
Summary

- We have shown the muon magnetic moment in 3σ significance. 2006.04822



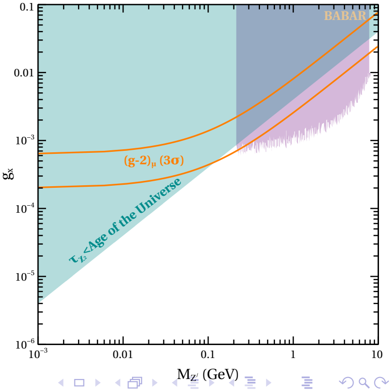
Summary

- We have shown the muon magnetic moment in 3σ significance. 2006.04822
- The lifetime of χ_2 puts a strong bound.



Summary

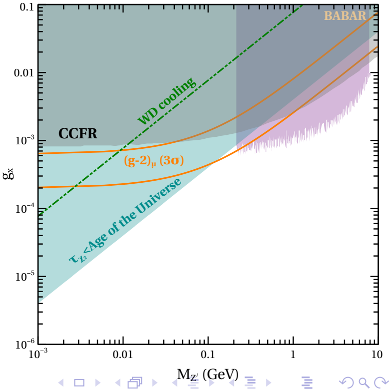
- We have shown the muon magnetic moment in 3σ significance. 2006.04822
- The lifetime of χ_2 puts a strong bound.
- The strongest bound in the high mass regime of Z' comes from BABAR observations for 4μ final states. 1606.03501



Summary

- We have shown the muon magnetic moment in 3σ significance. 2006.04822
- The lifetime of χ_2 puts a strong bound.
- The strongest bound in the high mass regime of Z' comes from BABAR observations for 4μ final states. 1606.03501

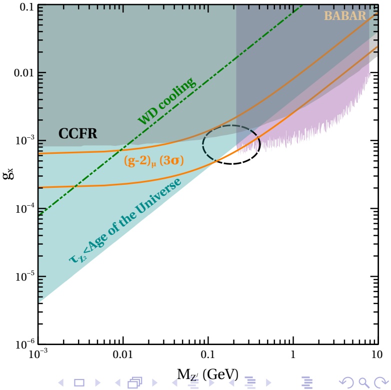
- Upper bound on cross sections for $\nu N \to \nu N \overleftarrow{\mu}\,\mu$ measured by CCFR and WD cooling bounds are also applicable. 1406.2332



Summary

- We have shown the muon magnetic moment in 3σ significance. 2006.04822
- The lifetime of χ_2 puts a strong bound.
- The strongest bound in the high mass regime of Z' comes from BABAR observations for 4μ final states. 1606.03501

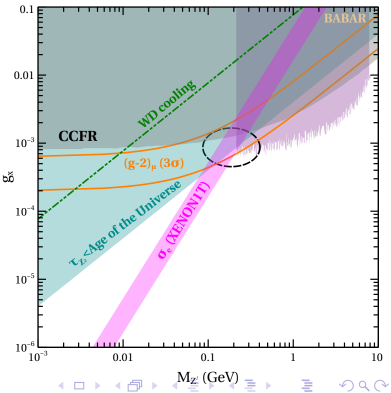
- Upper bound on cross sections for $\nu N \to \nu N \overleftarrow{\mu} \mu$ measured by CCFR and WD cooling bounds are also applicable. 1406.2332



Summary

- We have shown the muon magnetic moment in 3σ significance. 2006.04822
- The lifetime of χ_2 puts a strong bound.
- The strongest bound in the high mass regime of Z' comes from BABAR observations for 4μ final states. 1606.03501

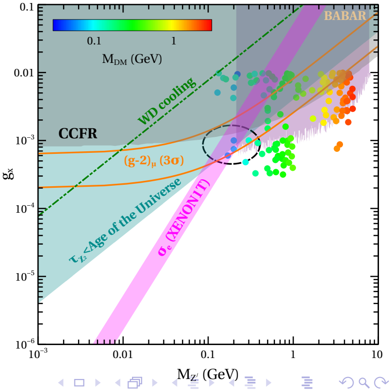
- Upper bound on cross sections for $\nu N \to \nu N \overleftarrow{\mu}\mu$ measured by CCFR and WD cooling bounds are also applicable. 1406.2332
- The required σ_e to fit the XENON1T excess can be achieved.



Summary

- We have shown the muon magnetic moment in 3σ significance. 2006.04822
- The lifetime of χ_2 puts a strong bound.
- The strongest bound in the high mass regime of Z' comes from BABAR observations for 4μ final states. 1606.03501

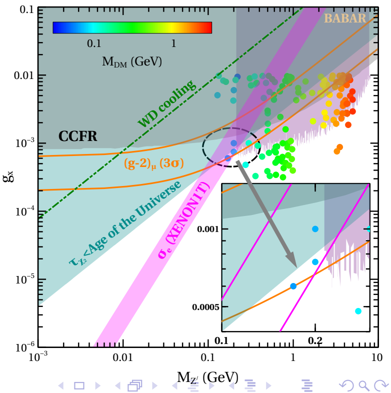
- Upper bound on cross sections for $\nu \mathrm{N} \to \nu \mathrm{N} \overleftarrow{\mu} \mu$ measured by CCFR and WD cooling bounds are also applicable. 1406.2332
- The required σ_e to fit the XENON1T excess can be achieved.
- Finaly, we have shown the parameter space coming from the DM analysis.



Summary

- We have shown the muon magnetic moment in 3σ significance. 2006.04822
- The lifetime of χ_2 puts a strong bound.
- The strongest bound in the high mass regime of Z' comes from BABAR observations for 4μ final states. 1606.03501

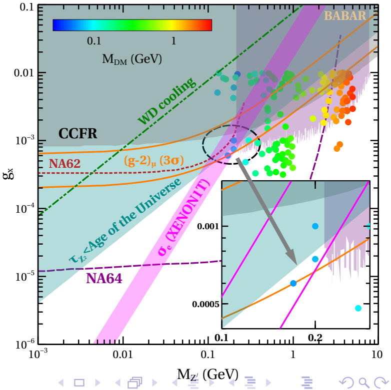
- Upper bound on cross sections for $\nu N \to \nu N \overleftarrow{\mu} \mu$ measured by CCFR and WD cooling bounds are also applicable. 1406.2332
- The required σ_e to fit the XENON1T excess can be achieved.
- Finaly, we have shown the parameter space coming from the DM analysis.



Summary

- We have shown the muon magnetic moment in 3σ significance. 2006.04822
- The lifetime of χ_2 puts a strong bound.
- The strongest bound in the high mass regime of Z' comes from BABAR observations for 4μ final states. 1606.03501

- Upper bound on cross sections for $\nu N \to \nu N \overleftarrow{\mu} \mu$ measured by CCFR and WD cooling bounds are also applicable. 1406.2332
- The required σ_e to fit the XENON1T excess can be achieved.
- Finaly, we have shown the parameter space coming from the DM analysis.



Conclusions

Motivated by the recently reported excess in electron recoil events by the XENON1T collaboration

- We propose an inelastic fermion dark matter (DM) scenario within the framework of a gauged $\mathrm{L}_\mu - \mathrm{L}_\tau$ model.
- The model can also accommodate tiny neutrino masses as well as anomalous muon magnetic moment $(\mathrm{g}-2)_\mu$.
- The inelastic down scattering of heavier DM component can give rise to the XENON1T excess for keV scale mass splitting with lighter DM component.
- A tiny parameter space consistent with all these bounds and requirements will face further scrutiny in near future experiments operating at different frontiers.


Stay Safe
and
Healthy


Thank
you!