Hints of Light New Physics at XENON1T and Muon g-2 Experiments

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Outline

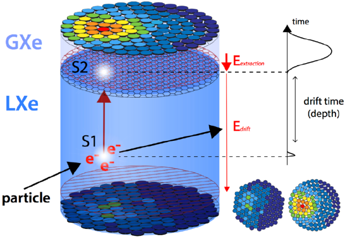
Based on work done in collaboration with :

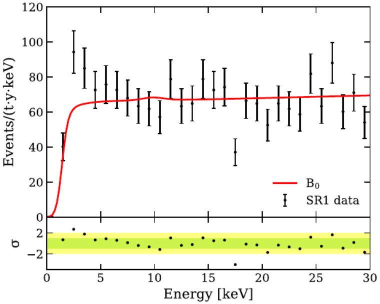
M. Lindner, Y. Mambrini & F. Queiroz
arxiv :2006.14590, Phys. Lett. B 811 (2020)

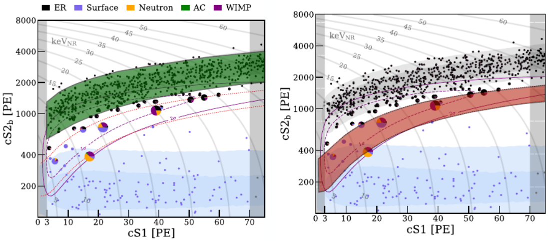
G. Arcadi, A. de Jesus, F. Queiroz & Y. Villamizar
arxiv :2104.04456

XENON1T Anomaly

- 3.3 σ excess in the low energy electron recoils
- 285 events observed in the region between 1-7 keV
  - 235 $\pm$ 15 events were expected

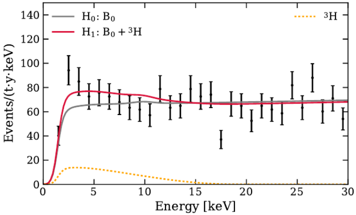




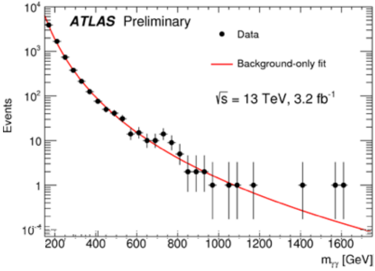


What is behind this excess ?

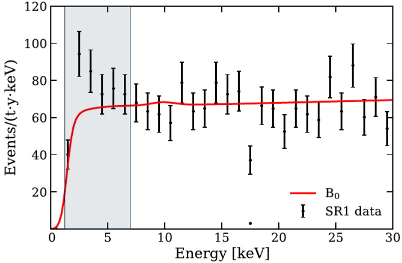
- Background ?
  - Tritium β-decay
  - Concentration : $(6.2\pm$ 2.0) $\times 10^{-25}$ mol/mol (3 atoms of tritium per kg of xenon)
  - Could account for 159 ± 51 events



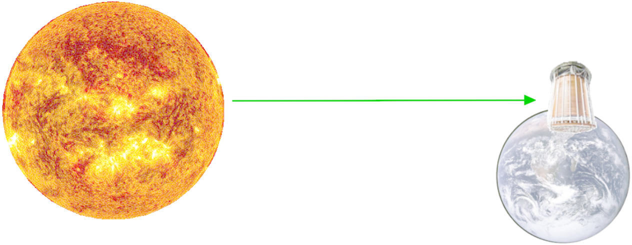
- Statistical fluctuation ?

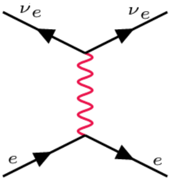


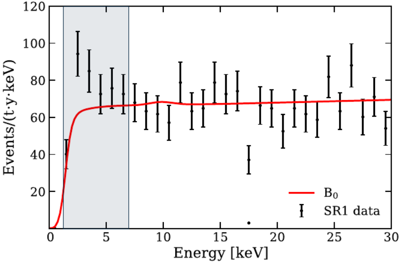
- The excess is localized near threshold

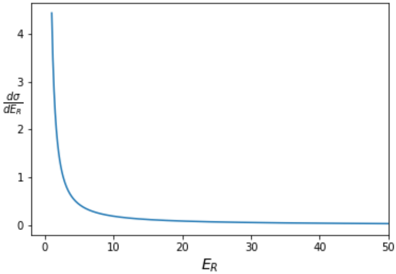


Solar Neutrinos + New Interaction









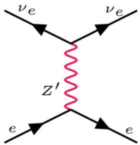
$\nu - e$ scattering via Z'

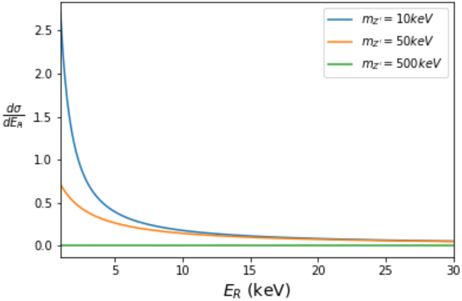
- Simplified coupling :

$$\mathcal{L}_{Z'ff} \supset (\frac{g_\nu}{4}\bar{\nu}\gamma^\mu\nu + \frac{g_e}{4}\bar{l}\gamma^\mu l)Z'$$

- Cross section :

$$\frac{d\sigma_\nu}{dE_R} \simeq \frac{m_e g_\nu^2 g_e^2}{512\pi(2E_R m_e + m_{Z'}^2)^2}$$





$\nu - e$ scattering via Z'

- Assume :

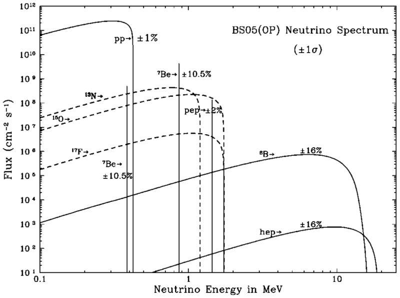
$$g_e = g_\nu \equiv g \quad , \quad m_{Z'} = 10keV \quad , \quad E_R \sim 5keV$$

$$\frac{d\sigma_\nu}{dE_R} \sim 10^{-8} g^4$$

- Differential rate :

$$\frac{dR}{dE_R} \propto N_T \int dE_\nu \frac{d\phi}{dE_\nu} \frac{d\sigma_\nu}{dE_R}$$

($N_T \sim 10^{29} t^{-1}, \Phi \sim 10^2 y^{-1} keV^{-2}$)



- For $\frac{dR}{dE_R} \sim 10$ events $\implies$ $g \sim 10^{-6} - 10^{-5}$

2HDM-$U(1)_{B-L}$

Two Higgs doublets :

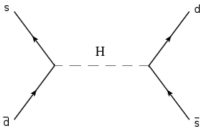
$$\Phi_1 = \begin{pmatrix} \phi_1^+ \\ \phi_1^0 \end{pmatrix}, \qquad \Phi_2 = \begin{pmatrix} \phi_2^+ \\ \phi_2^0 \end{pmatrix}$$

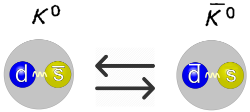
A motivation to introduce the $U(1)$ symmetry in the 2HDM is the flavor problem

Neutral scalars mediate flavor changing neutral interactions at tree level

General Yukawa Lagrangian with two scalar doublets :

$$-\mathcal{L}_{Y_{\text{2HDM}}} = y^{1d}\bar{Q}\Phi_1 d_R + y^{1u}\bar{Q}\widetilde{\Phi_1} u_R + y^{1e}\bar{L}\Phi_1 e_R + \\ + y^{2d}\bar{Q}\Phi_2 d_R + y^{2u}\bar{Q}\widetilde{\Phi_2} u_R + y^{2e}\bar{L}\Phi_2 e_R + h.c.$$

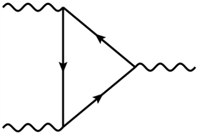




2HDM-$U(1)_{B-L}$

Particles	u_R	d_R	Q_L	L_L	e_R	N_R	Φ_2	Φ_1	Φ_S
$U(1)_{B-L}$ Charges	$1/3$	$1/3$	$1/3$	-1	-1	-1	0	2	2

- 3 right-handed neutrinos N_R for anomaly cancellation



- Scalar singlet Φ_S coupled to neutrinos

$$-\mathcal{L}_\nu \supset y^D \bar{L}\widetilde{\Phi}_2 N_R + Y^M \overline{N_R^c}\Phi_s N_R$$

- Neutrinos become massive after $U(1)$ breaking $\Longrightarrow$ Type I seesaw mechanism

Z ′ Interactions :

$$\mathcal{L}_{Z'ff} = \frac{1}{2} g \left(\bar{\nu}\gamma^\mu \nu + \bar{l}\gamma^\mu l\right) Z'_\mu + \dots$$

$$g_\nu = 2g \quad , \quad g_e = 2g$$

2HDM-$U(1)_{B-L}$

Z $'$ Mass :

$$m_{Z'} \sim g v_s$$

$m_{Z'}$ and g are not independent.

For $g = 10^{-6}$, $v_S = 1$ TeV $\quad\Longrightarrow\quad m_{Z'} \sim 1$ MeV. Too heavy !

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$U(1)_Y \otimes U(1)_{B-L}$ **Kinetic mixing** :

$$\epsilon \hat{F}'_{\mu\nu} \hat{F}^{\mu\nu} \quad \implies \quad \mathcal{L}_{Z'ff} = -\epsilon e J^{\mu}_{em} Z'_{\mu}$$

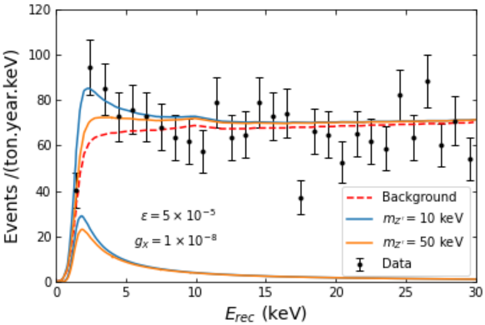
$$g_\nu = 2g \quad , \quad g_e = 2g + 4\epsilon e$$

2HDM-$U(1)_{B-L}$

- χ^2-fit for the 29 bins in the range $1-30$ keV of electron recoil energy

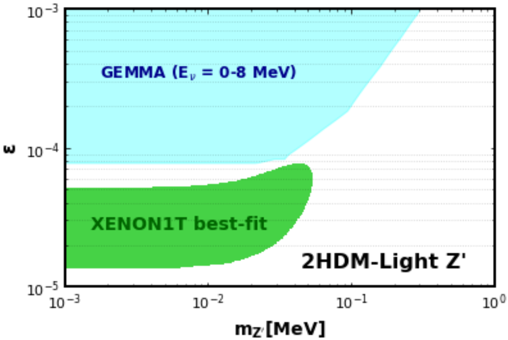
$$\chi^2 = \sum_i \frac{1}{\sigma_i^2}\left[\left(\frac{dR^{\text{th}}}{dE_{rec}}\right)_i - \left(\frac{dR^{exp}}{dE_{rec}}\right)_i\right]^2$$

- Sample signals for $m_{Z'} = 10keV$ and $m_{Z'} = 50keV$



2HDM-$U(1)_{B-L}$

- Favored region in the plane $\epsilon \times m_{Z'}$, assuming fixed $g = 1 \times 10^{-8}$



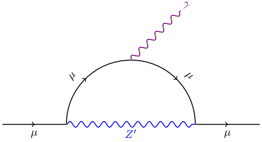
2HDM-$U(1)_{B-L}$ and $(g-2)_\mu$ Anomaly

- A 4.2σ discrepancy :

$$a_\mu^{exp} = 116592061(41) \times 10^{-11} \quad , \quad a_\mu^{SM} = 116591810(43) \times 10^{-11}$$

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

- Z' contribution :



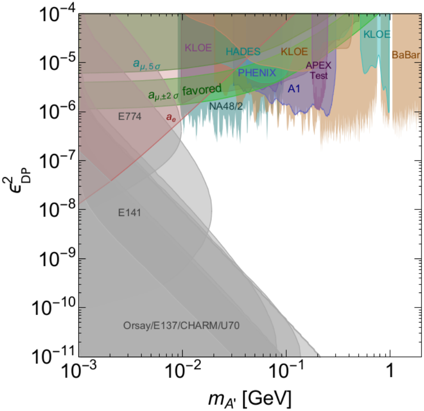
$$\Delta a_\mu = \frac{\epsilon^2 m_\mu^2}{8\pi^2} \int_0^1 \frac{2x^2(1-x)}{x^2 {m_\mu}^2 + (1-x) m_{Z'}^2} dx$$

- For $m_{Z'} \ll m_\mu$:

$$\Delta a_\mu \sim \frac{\epsilon^2}{8\pi^2} \quad \Longrightarrow \quad \epsilon \sim 10^{-3}$$

2HDM-$U(1)_{B-L}$ and $(g-2)_\mu$ Anomaly

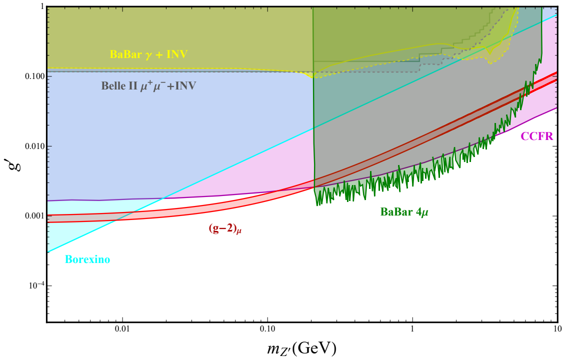
- Dark photon-like Z' is excluded as an explanation for the $(g-2)_\mu$



2HDM-$U(1)_{L_\mu - L_\tau}$

Particles	u	d	e	μ	τ	ν_e	ν_μ	ν_τ	Φ_2	Φ_1
$U(1)_{L_\mu - L_\tau}$ Charges	0	0	0	1	-1	0	1	-1	0	1

$$-\mathcal{L}_{Z'ff} = \frac{1}{2} g' \left(\bar{\mu}\gamma^\mu \mu - \bar{\tau}\gamma^\mu \tau \right) Z'_\mu + \ldots$$



- Z' mass in the range $10\text{MeV} \lesssim m_{Z'} \lesssim 200\text{MeV}$

Summary

- XENON1T experiment has observed an excess on electronic recoils which is not the signal expected from a WIMP
- It may be related to neutrino physics if new light mediators enhance the interaction of solar neutrinos with electrons at low energies
- We propose a complete model that realizes this idea to account for the XENON1T signal
- A modified version of the model can accommodate the $(g-2)_\mu$ anomaly, although not both anomalies simultaneously