

# Seesaw vector-like leptons for muon g-2, W boson mass, and dark matter Kimiko Yamashita

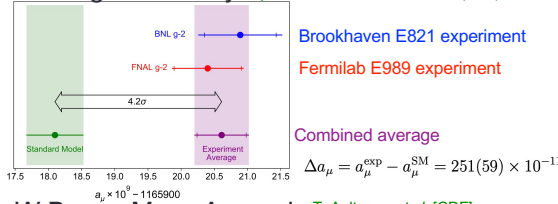
Collaborators: Hyun Min Lee *Eur. Phys. J.* 82, no.8, 661 (2022) (arXiv: 2204.05024)

Seong-Sik Kim, Hyun Min Lee, Adriana G. Menkara *Phys. Rev. D* 106, no.1, 015008 (2022) (arXiv: 2205.04016)

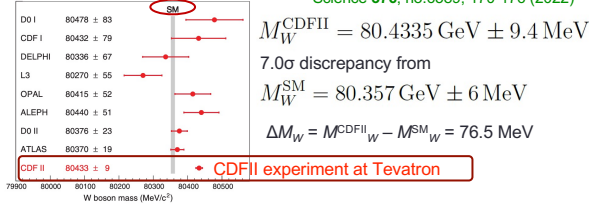
Chung-Ang University 

## Muon g-2 and W boson Mass Anomalies 1

• Muon g-2 anomaly B. Abi et al. [Muon g-2], Phys. Rev. Lett. 126, no.14, 141801 (2021)



• W Boson Mass Anomaly T. Aaltonen et al. [CDF], Science 376, no.6589, 170-176 (2022)



## Field Contents, Symmetry, Lagrangian 2

• U(1)' symmetry (spontaneously broken) <sup>New</sup>

	$q_L$	$u_R$	$d_R$	$l_L$	$e_R$	$H$	$H'$	$E_L$	$E_R$	$\phi$
U(1)'	0	0	0	0	0	0	+2	-2	-2	-2

Z' boson as U(1)' gauge boson

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}^2 - \frac{1}{2}\sin\xi F_{\mu\nu}^{\prime 2} + |D_\mu\phi|^2 + |D_\mu H|^2 - V(\phi, H, H') + \mathcal{L}_{\text{fermions}}$$

$\rightarrow$  Mass mixing  
 $\rightarrow$  b/w Z and Z' bosons

$$V(\phi, H, H') = \mu_1^2 H^\dagger H + \mu_2^2 H'^\dagger H' + (\mu_3\phi H^\dagger H' + \text{h.c.}) + \lambda_1(H^\dagger H)^2 + \lambda_2(H'^\dagger H')^2 + \lambda_3(H^\dagger H)(H'^\dagger H') + \mu_\phi^2\phi^*\phi + \lambda_\phi(\phi^*\phi)^2 + \lambda_{H\phi}H^\dagger H\phi^*\phi + \lambda_{H'\phi}H'^\dagger H'\phi^*\phi$$

$$\mathcal{L}_{\text{fermions}} = \sum_{i=SM,E} i\bar{\psi}_i\gamma^\mu D_\mu\psi_i - y_u\bar{q}_L d_R H - y_d\bar{q}_L u_R \bar{H} - y_l\bar{l}_L e_R H - M_E\bar{E}E - \lambda_E\phi\bar{E}E - y_E\bar{l}_L E_R H' + \text{h.c.}$$

$\rightarrow$  Mass mixing in a muon sector

## Seesaw Mechanism 3

$$\mathcal{L}_{L,\text{mass}} = -M_E\bar{E}E - m_0\bar{e}e - (m_R\bar{E}_L e_R + m_L\bar{e}_L E_R + \text{h.c.})$$

• After diagonalizing the mass matrix

$$\begin{pmatrix} e_R \\ E_R \end{pmatrix} = \begin{pmatrix} \cos\theta_R & \sin\theta_R \\ -\sin\theta_R & \cos\theta_R \end{pmatrix} \begin{pmatrix} l_{1R} \\ l_{2R} \end{pmatrix}, \begin{pmatrix} e_L \\ E_L \end{pmatrix} = \begin{pmatrix} \cos\theta_L & \sin\theta_L \\ -\sin\theta_L & \cos\theta_L \end{pmatrix} \begin{pmatrix} l_{1L} \\ l_{2L} \end{pmatrix}$$

$$\mathcal{L}_{L,\text{mass}} = -m_{l_1}\bar{l}_1 l_1 - m_{l_2}\bar{l}_2 l_2$$

• taking  $m_{l_2} \simeq M_E$  for  $m_0, m_R, m_L \ll M_E$ ,  $m_{l_1} \approx m_0 - \frac{m_R m_L}{M_E}$

• For  $M_E \gg m_0 m_L / m_R, m_0 m_R / m_L$ , • if  $\frac{m_R m_L}{M_E} \lesssim m_{l_1}$  and  $m_R, m_L \ll M_E$ ,

$$\sin(2\theta_R) \simeq \frac{2M_E m_R}{m_{l_2}^2 - m_{l_1}^2} \simeq \frac{2m_R}{M_E}$$

$$\sin(2\theta_L) \simeq \frac{2M_E m_L}{m_{l_2}^2 - m_{l_1}^2} \simeq \frac{2m_L}{M_E}$$

$$m_{l_1} \sim \frac{m_R m_L}{M_E} \simeq \theta_R \theta_L M_E$$

$$\theta_R \theta_L \sim m_{l_1} / M_E$$

## Z' boson Contribution 4

$$\mathcal{L}_{L,\text{eff}} \supset (g_{Z'} Z'_\mu \bar{l}\gamma^\mu (c_V + c_A\gamma^5)E + \text{h.c.})$$

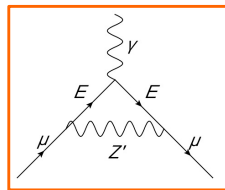
$$c_V = \frac{1}{2}(\sin 2\theta_R + \sin 2\theta_L)$$

$$c_A = \frac{1}{2}(\sin 2\theta_R - \sin 2\theta_L)$$

Large  
 $\Delta a_\mu^{Z',E} \simeq \frac{g_{Z'}^2 M_E m_\mu}{16\pi^2 m_{Z'}^2} (c_V^2 - c_A^2)$

Small  
Enhancement

$$M_E \gg m_{Z'} \gg m_\mu$$



$$c_V^2 - c_A^2 \sim 4\theta_L\theta_R \sim 4\frac{m_\mu}{M_E}$$

From our seesaw scenario

$$\Delta a_\mu^{Z',E} \propto g_{Z'}^2 m_\mu^2 / m_{Z'}^2$$

Chiral enhancement & the coupling by seesaw mechanism make  $\Delta a$  independent from  $M_E$  for  $M_E \gg m_{Z'} \gg m_\mu$

## Results for Muon g-2 & W boson mass 5

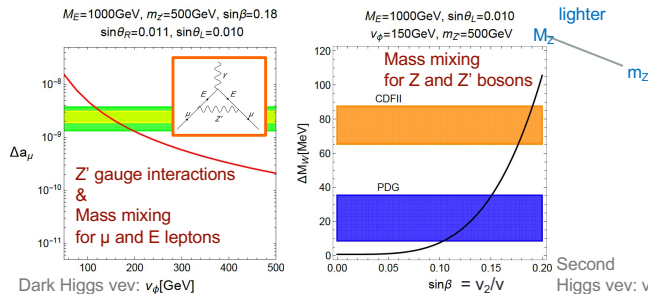
$$\Delta a_\mu^{Z',E} \propto g_{Z'}^2 m_\mu^2 / m_{Z'}^2$$

$$m_{Z'}^2 = g_{Z'}^2 (8v_\phi^2 + 4v_2^2)$$

$$\Delta M_W \simeq \frac{1}{2} M_W \frac{s_W^2}{c_W^2 - s_W^2} (1 - \cos\theta_L - (\Delta r)_{\text{new}})$$

$$(\Delta r)_{\text{new}} = -\frac{c_W^2}{s_W^2} (\Delta\rho_L + \Delta\rho_H)$$

$$\Delta\rho_H \simeq \begin{cases} \frac{16g_{Z'}^2 M_2^2}{9s_W^2} \sin^4\beta, & m_{Z'} \gg M_Z, \\ -\frac{16g_{Z'}^2 M_2^2}{9s_W^2} \sin^4\beta, & m_{Z'} \ll M_Z. \end{cases}$$



## Extension to SU(2)' model 6

	$q_L = \begin{pmatrix} u_L \\ d_L \end{pmatrix}$	$u_R$	$d_R$	$l_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	$e_R$	$H = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$
SU(2) <sub>D</sub> × G <sub>EW</sub>	(1,2) <sub>1/3</sub>	(1,1) <sub>2/3</sub>	(1,1) <sub>-1/3</sub>	(1,2) <sub>-1/2</sub>	(1,1) <sub>-1</sub>	(1,2) <sub>1/2</sub>
Z <sub>2</sub>	+	+	+	+	+	+

	$\nu_R = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$	$\Psi = \begin{pmatrix} E' \\ E \end{pmatrix}$	$\Phi_D = \begin{pmatrix} \phi_1 \\ \phi_2 \end{pmatrix}$	DM $V = \begin{pmatrix} V^+ \\ V^0 \\ V^- \end{pmatrix}$	
SU(2) <sub>D</sub> × G <sub>EW</sub>	(1,1) <sub>0</sub>	(2,2) <sub>1/3</sub>	(2,1) <sub>-1</sub>	(2,1) <sub>0</sub>	(3,1) <sub>0</sub>
Z <sub>2</sub>	+	(- +)	(+)	(+)	(+)

Cause mixing btw Z and Z' VL-lepton mixing with muon

