Exploring Non-SUSY New Physics in Polarised Møller Scattering

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Introduction

Left-right asymmetry, A_{LR}, very clean probe of new physics.

$$A_{LR} \equiv \frac{d\sigma_L - d\sigma_R}{d\sigma_L + d\sigma_R}$$

Current measurement [SLAC E158 05]:

$$A_{LR} = 131 \pm 14\,(\text{stat}) \pm 10\,(\text{syst})\,\text{ppb}$$

When the 12 GeV upgrade at JLAB completed, precision 1 ppb measurement will be possible.

- Sensitive to the existence of extra Z' gauge bosons and doubly charged scalars at several TeV range.
- Provide complementary information to LHC direct measurements.

Results from PAMELA and FERMI points to possibility of a low-scale hidden sector.

- Can probe GeV range hidden sector new physics.

Effective Operators

A systematic and model-independent way to parametrise new physics at scale $\Lambda > v$:

$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_6$$

$$\begin{aligned}-2\mathcal{L}_6 = & \frac{c_{LL}}{\Lambda^2}(\bar{L}_a\gamma^\mu L_a)(\bar{L}_b\gamma_\mu L_b) + \frac{c_{LR}}{\Lambda^2}(\bar{L}_a\gamma^\mu L_a)(\bar{e}_R\gamma_\mu e_R) + \\ & \frac{c_{RR}}{\Lambda^2}(\bar{e}_R\gamma^\mu e_R)(\bar{e}_R\gamma_\mu e_R) + \frac{d_{LL}}{\Lambda^2}(\bar{L}_a\gamma^\mu L_b)(\bar{L}_b\gamma_\mu L_a) \\ & + h.c.\end{aligned}$$

Relevant operators contributing to A_{LR}:

$$\mathcal{O}_1 = \bar{e}\gamma^\mu \hat{L} e\, \bar{e}\gamma_\mu \hat{L} e\,, \quad \mathcal{O}_2 = \bar{e}\gamma^\mu \hat{R} e\, \bar{e}\gamma_\mu \hat{R} e$$

$\hat{L}$, $\hat{R}$ chiral projectors.

For $\Lambda^2 \gg s \gg m_e^2$ valid for 12 GeV experiments:

$$\begin{aligned}A_{LR} &= A_{LR}^{\mathrm{SM}} + \delta A_{LR} \\ &= \frac{4G_\mu s}{\sqrt{2}\pi\alpha}\frac{y(1-y)}{1+y^4+(1-y)^4} \\ &\quad \times \left[\left(\frac{1}{4} - \sin^2\theta_{\mathrm{W}}^{\overline{\mathrm{MS}}}\right) + \frac{c'_{LL} - c_{RR}}{4\sqrt{2}G_\mu\Lambda^2}\right]\end{aligned}$$

$y = Q^2/s$, $s = 2m_e E_{beam}$, $c'_{LL} = c_{LL} + d_{LL}$.

Useful variable:

$$\delta_{LR} \equiv \frac{\delta A_{LR}}{A_{LR}^{SM}} = \frac{c'_{LL} - c_{RR}}{\sqrt{2}G_\mu(1 - 4\sin^2\theta_{\mathrm{W}}^{\overline{\mathrm{MS}}})\Lambda^2}$$

New Physics Scenarios

High scale new physics, couples directly to SM:

- GUT models
- Left-right symmetric models
- Bottom-up $U(1)_X$ models
- Models with doubly charged scalars.

New physics can be low scale, couples to SM only through mixings:

- Hidden sector/Shadow Z' models

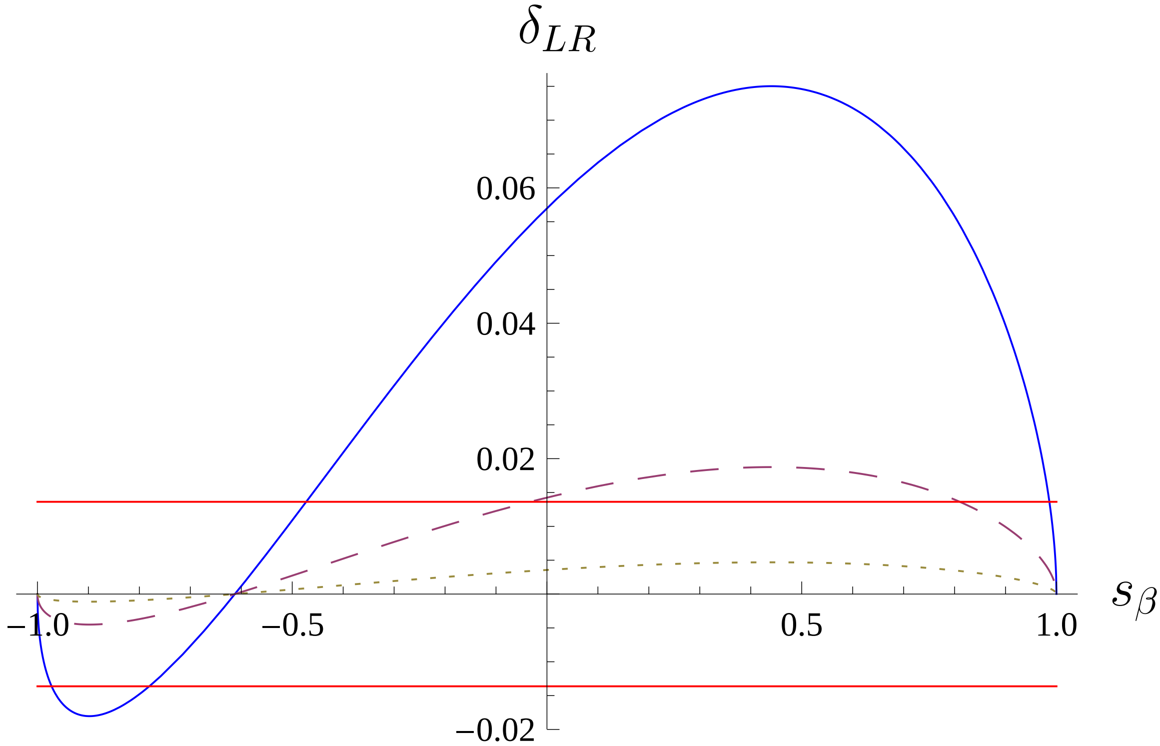
GUT Models

$$E_6 \to SO(10) \times U(1)_\psi \to SU(5) \times U(1)_\chi \times U(1)_\psi \to SM \times U(1)_\beta$$

$$X^\mu(\beta) = B^\mu_\psi \sin\beta + B^\mu_\chi \cos\beta, \quad c'_{LL} - c_{RR} = \frac{4\pi\alpha}{3c_W^2} c_\beta \left(c_\beta + \sqrt{\frac{5}{3}} s_\beta \right)$$

E158 95% **CL limits**: $-0.337 < \delta_{LR} < 0.122$.

JLAB 95% **CL limits**: $|\delta_{LR}| < 0.0136$ (projected assuming 1 ppb total 1σ error).



Solid, dashed and dotted lines denote $\Lambda = 1, 2, 4$ TeV.

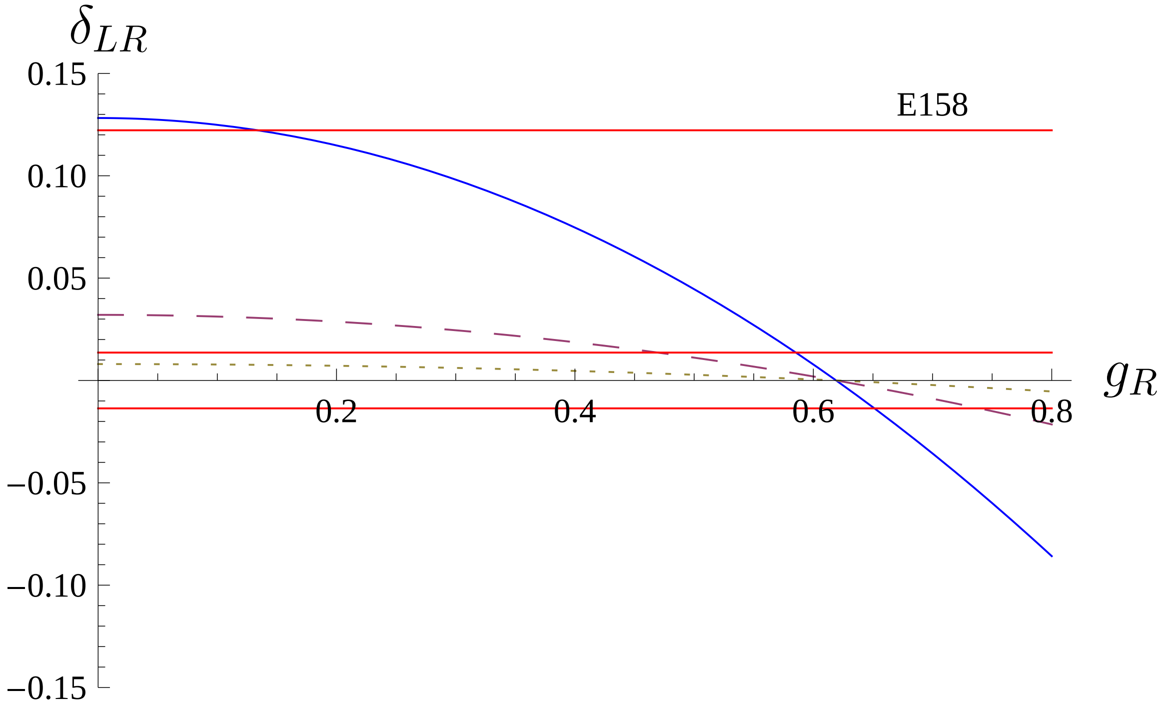
Horizontal lines projected JLAB upper and lower limits.

LR Symmetric Models

$$SU(2)_L \times SU(2)_R \times U(1)_{B-L} \rightarrow SU(2)_L \times U(1)_R \times U(1)_{B-L}$$

$$c'_{LL} - c_{RR} = \frac{1}{4}\left(3g_Y^2 - g_R^2\right)$$

Note $\delta_{LR} \neq 0$ even if $g_R = g_L$.



Solid, dashed and dotted lines denote $\Lambda = 1$, 2, 4 TeV.

Narrow band projected JLAB limits.

Bottom-up $U(1)_X$ Models

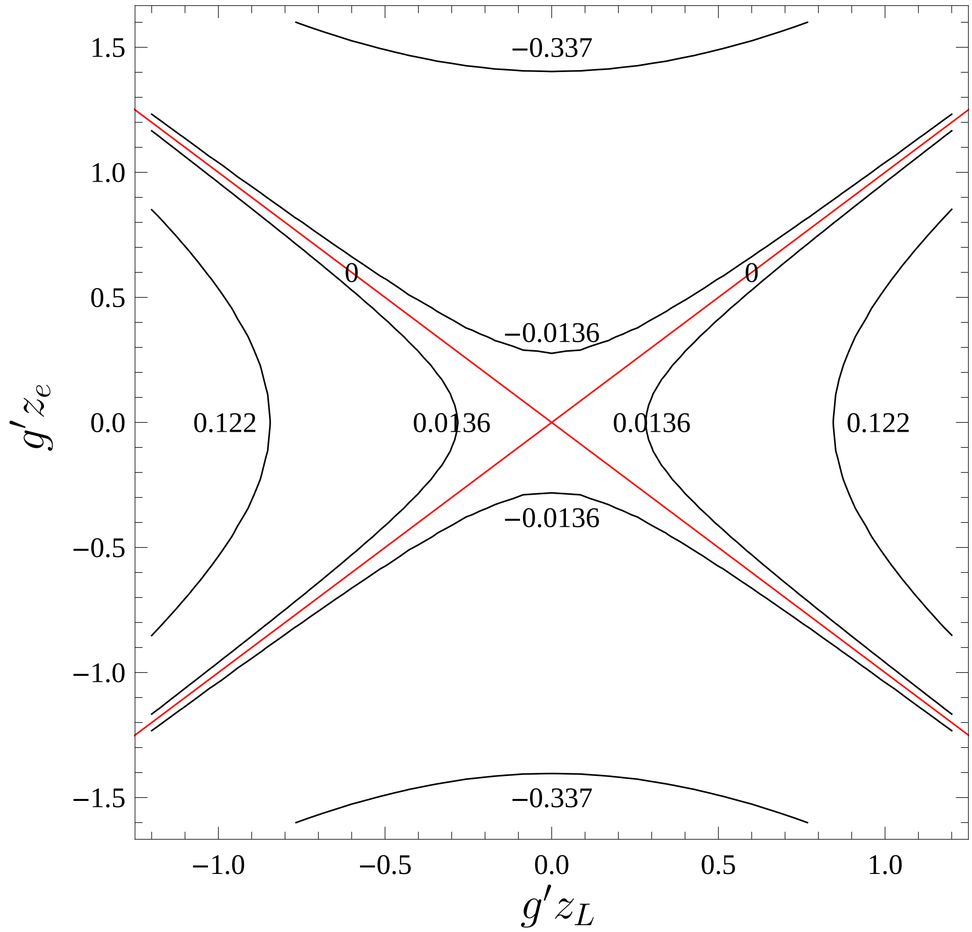
Extra $U(1)$ factor unrelated to larger broken down symmetry.

SM charges under $U(1)_X$ determined by **anomaly cancellation**:

$$z_Q = -\frac{1}{3} z_L\,, \quad z_u = \frac{2}{3} z_L - z_e\,, \quad z_d = -\frac{4}{3} z_L + z_e$$
$$z_N = 2 z_L - z_e\,, \quad z_H = z_L - z_e$$

General case: $z_L \neq z_e$, $c'_{LL} - c_{RR} = g'^2 (z_L^2 - z_e^2)$

$U(1)_X = U(1)_{B-L}$: $z_L = z_e \Rightarrow \delta A_{LR} = 0$



Contours of constant δ_{LR} for $\Lambda = 1$ TeV (other values of Λ obtained simply by a rescaling factor Λ/TeV).

Doubly Charged Scalars

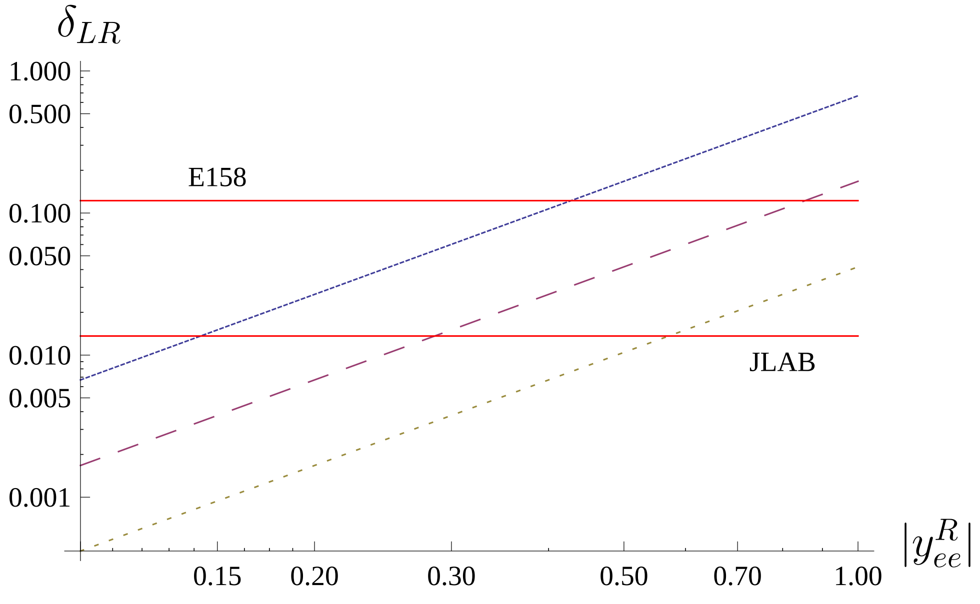
$P^{\pm\pm}$ motivated by Type II seesaw neutrino mass generation mechanisms.

$P^{\pm\pm}$ $SU(2)_L$ singlet:

$$\frac{|y_{ee}^R|^2}{4M_P^2}(\bar{e}\gamma^\mu \hat{R}e)(\bar{e}\gamma_\mu \hat{R}e) \Rightarrow \delta_{LR} = \frac{|y_{ee}^R|^2}{2\sqrt{2}(1-4s_W^2)G_\mu M_P^2}$$

$P^{\pm\pm}$ $SU(2)_L$ doblet:

- Like singlet case but with LL-type Wilson coefficients.
- $\delta_{LR} < 0$!



Solid, dashed and dotted lines denote $M_P = 1$, 2, 4 TeV.

Hidden Sector/Shadow Z' Models

Extra $U(1)$ hidden sector gauge symmetry, which communicate with the SM only through scalar mixing and gauge kinetic mixing **[Kumar and Wells 06, CNW 06]**.

Gauge kinetic mixing:

$$\frac{\epsilon}{2} X_{\mu\nu} B^{\mu\nu} \Rightarrow \begin{pmatrix} X \\ B \end{pmatrix} = \begin{pmatrix} c_\epsilon & 0 \\ -s_\epsilon & 1 \end{pmatrix} \begin{pmatrix} X' \\ B' \end{pmatrix}, \quad s_\epsilon = \frac{\epsilon}{\sqrt{1-\epsilon^2}}$$

$$\begin{pmatrix} B' \\ W_3 \\ X' \end{pmatrix} = \begin{pmatrix} c_W & -s_W & 0 \\ s_W & c_W & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_\eta & -s_\eta \\ 0 & s_\eta & c_\eta \end{pmatrix} \begin{pmatrix} \gamma \\ Z \\ Z' \end{pmatrix}$$

$$\tan 2\eta = \frac{2 s_W s_\epsilon}{(c_W M_X / M_W)^2 + s_W^2 s_\epsilon^2 - 1}$$

Gauge-fermion couplings:

$$Z^\mu \bar{f} f: \quad i\gamma^\mu \frac{g_L}{c_W} \left\{ \left[c_\eta (T^3_{f_L} - s_W^2 Q_{f_L}) - \frac{1}{2} s_\eta s_W s_\epsilon Y_{f_L} \right] \hat{L} + (L \leftrightarrow R) \right\}$$

$$Z'^\mu \bar{f} f: \quad -i\gamma^\mu \frac{g_L}{c_W} \left\{ \left[s_\eta (T^3_{f_L} - s_W^2 Q_{f_L}) + \frac{1}{2} c_\eta s_W s_\epsilon Y_{f_L} \right] \hat{L} + (L \leftrightarrow R) \right\}$$

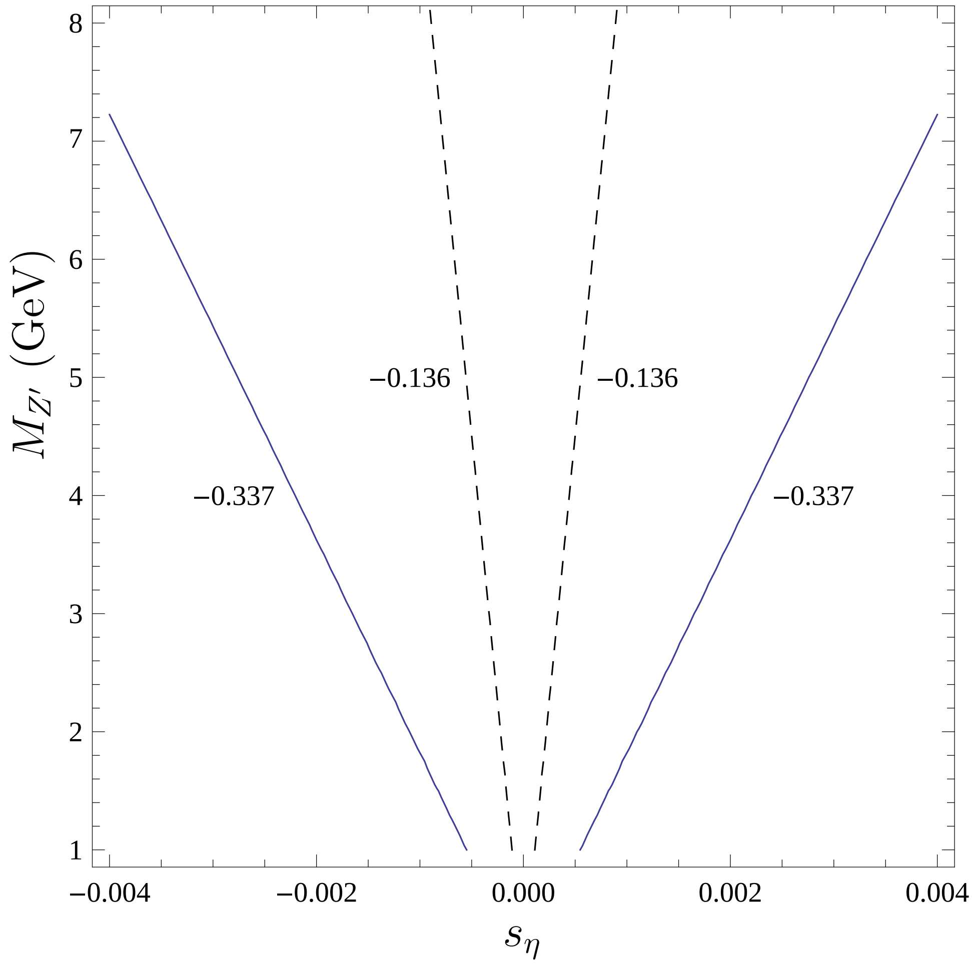
Low scale limit ($M_{Z'} \sim M_X \ll M_W$, $\eta \sim \epsilon$):

$$\delta_{LR} = \left(s_\eta^2 - 15.80 c_\eta^2 s_\epsilon^2 + 31.85 c_\eta s_\eta s_\epsilon \right) \frac{M_Z^2}{M_{Z'}^2}$$

Dominated by γ-Z' interference.

Light Shadow Z' $(M_{Z'} \ll M_W)$

$$s_\epsilon = -\frac{s_\eta}{s_W c_\eta}\left(1 - c_W^2 r^2\right) , \quad r = \frac{M_{Z'}}{M_W}$$



Contours of constant δ_{LR}. Solid and dashed contours denote E158 and projected JLAB lower limits.

NO PARAMETER SPACE EXISTS FOR $\delta_{LR} > 0$**!**.

Summary

Complementary probe of new physics to LHC at several TeV order

Given the mass of new states measured at the LHC:

- Clean determination of Z' gauge couplings to electrons and mixing parameters.

- Can shed light on the origin of the extra Z'.

- Clean determination of Yukawa couplings of doubly charged scalars to electrons.

- Sign of δ_{LR} can determine type of doubly charged scalars.

Probe low scale hidden sector

Provide valuable inputs to dark matter model building employing a hidden/shadow sector:

- Constrain mixing between SM Z and shadow Z'.

- Best measure of shadow Z' couplings to electrons.