Dark Gauge U(1) Symmetry for an Alternative Left-Right Model

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Overview

Introduction/Motivation

- Restore symmetry between Left-Right sectors
- Generate naturally small neutrino masses
- Accomodate dark matter

Minimal Left-Right Model

- Simple extention of the SM gauge group
- Spontaneous/Explicit breaking of P ($SU(2)_L \longleftrightarrow SU(2)_R$) (also CP)
- Genartion of naturaly light neutrino masses (Seesaw I/III)

$$SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$$

$$Q_L = \begin{pmatrix} u_L \\ d_L \end{pmatrix} \equiv [3,2,1,\frac{1}{3}] \quad Q_R = \begin{pmatrix} u_R \\ d_R \end{pmatrix} \equiv [3,1,2,\frac{1}{3}]$$
$$\ell_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix} \equiv [1,2,1,-1] \quad \ell_R = \begin{pmatrix} \nu_R \\ e_R \end{pmatrix} \equiv [1,1,2,-1].$$ *

- $\eta \sim$(1,2,2,0), $\Delta_L \sim$(1,3,1,-1), $\Delta_R \sim$(1,1,3,-1)
- Seesaw I/II
- $\eta \sim$(1,2,2,0), $\phi_L \sim$(1,2,1,1/2), $\phi_R \sim$(1,1,2,1/2)
- Double seesaw through Weinberg dim-5 operator
- Flavour changing neutral currents

*N.G. Deshpande et al., Phys. Rev. D 44, 837 (1991).

Alternative Left-Right Model

$$SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$$

$$\begin{aligned}
(u,d)_L &: (3,2,1,\tfrac{1}{6}) \quad (h^c,u^c)_L : (\bar{3},1,2,-\tfrac{1}{6}) \\
(\nu_E,E)_L &: (1,2,1,-\tfrac{1}{2}) \quad (e^c,n)_L : (1,1,2,\tfrac{1}{2}) \\
h_L &: (3,1,1,-\tfrac{1}{3}) \quad d^c_L : (\bar{3},1,1,\tfrac{1}{3}) \\
\begin{pmatrix} \nu_e & E^c \\ e & N^c_E \end{pmatrix}_L &: (1,2,2,0) \qquad N^c_L : (1,1,1,0),
\end{aligned}$$ [†]

- ALRM is motivated by superstring-inspired E_6 model
- Flavour changing neutral currents are naturaly absent tree level
- $W^{\pm}_R$ has lepton number ± 1 and odd parity so they do not mix with $W^{\pm}_L$
- $SU(2)_R$ breaking scale can be below as TeV, $W^{\pm}_R$ and Z' are reachiable at LHC

[†] E. Ma, Phys. Rev. D 36, 274 (1987); K. S. Babu, X.-G. He, and E. Ma, Phys. Rev. D 36, 878 (1987); J. L. Hewett and T. G. Rizzo,

Fermion	$SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)$	S
$\psi_L = (\nu, e)_L$	(1, 2, 1, − 1/2)	1
$\psi_R = (n, e)_R$	(1, 1, 2, −1/2)	1/2
$Q_L = (u, d)_L$	(3, 2, 1, 1/6)	0
$Q_R = (u, h)_R$	(3, 1, 2, 1/6)	1/2
d_R	(3, 1, 1, − 1/3)	0
h_L	(3, 1, 1, − 1/3)	1

Scalar	$SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)$	S
Φ	(1, 2, 2, 0)	1/2
$\tilde{\Phi} = \sigma_2 \Phi^* \sigma_2$	(1, 2, 2, 0)	−1/2
Φ_L	(1, 2, 1,1/2)	0
Φ_R	(1, 1, 2,1/2)	−1/2
Δ_L	(1, 3, 1, 1)	−2
Δ_R	(1, 1, 3, 1)	−1 ‡

- No tree level FCNC
- Neutrino masses($m_\nu \sim \langle \Delta_L^0 \rangle \implies$ L $\rightarrow$ $(-1)^L$, R parity)
- Fermionic Dark Matter (Scotinos) ($m_n \sim \langle \Delta_R^0 \rangle$)
- Lepton number given by L=S-T_{3R}
- $\langle \phi_1^0 \rangle = 0$ by S-T_{3R}
- h, $W_R^\pm$ has L=1,$\mp$1
- SM particles are even, n, h, $W_R^\pm$, and $\Delta_R^\pm$ are odd under parity

‡ S. Khalil, H.-S. Lee, E. Ma, Phys. Rev. D 79, 041701(R) (2009)

Fermion	$SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)$	S
$\psi_L = (\nu, e)_L$	(1, 2, 1, −1/2)	1
$\psi_R = (n, e)_R$	(1, 1, 2, −1/2)	3/2
ν_R	(1, 1, 1, 0)	1
n_L	(1, 1, 1, 0)	2
$Q_L = (u, d)_L$	(3, 2, 1, 1/6)	0
$Q_R = (u, h)_R$	(3, 1, 2, 1/6)	−1/2
d_R	(3, 1, 1, −1/3)	0
h_L	(3, 1, 1, −1/3)	−1

Scalar	$SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)$	S
Φ	(1, 2, 2, 0)	−1/2
$\tilde{\Phi} = \sigma_2 \Phi^* \sigma_2$	(1, 2, 2, 0)	1/2
Φ_L	(1, 2, 1, 1/2)	0
Φ_R	(1, 1, 2, 1/2)	1/2

§

- No tree level FCNC
- Dirac neutrino masses($m_\nu \sim \langle \phi_L^0 \rangle$)
- Dirac Fermionic Dark Matter (Scotinos) ($m_n \sim \langle \phi_R^0 \rangle$)
- Lepton number given by L=S+T$_{3R}$ and is conserved
- $\langle \phi_1^0 \rangle = 0$ by S+T$_{3R}$
- $\nu_R \nu_R$ breaks L and generates Majorana neutrino mass through canonical seesaw
- n remains Dirac fermion protected by residual global U(1) (n, $W_R^+ \sim$1, h, $\phi_1^{0,-} \sim$-1)

§ S. Khalil, H.-S. Lee, E. Ma, Phys. Rev. D 81, 051702(R) (2010)

Particle Content of the U(1)$_D$ ALRM

Gauge U(1)$_D$ Symmetry for ALRM

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particles	$SU(3)_C$	$SU(2)_L$	$SU(2)_R$	$U(1)_X$	$U(1)_S$
$(u,d)_L$	3	2	1	1/6	0
$(u,h)_R$	3	1	2	1/6	−1/2
d_R	3	1	1	−1/3	0
h_L	3	1	1	−1/3	−1
$(\nu,l)_L$	1	2	1	−1/2	0
$(n,l)_R$	1	1	2	−1/2	1/2
ν_R	1	1	1	0	0
n_L	1	1	1	0	1
(ϕ_L^+,ϕ_L^0)	1	2	1	1/2	0
(ϕ_R^+,ϕ_R^0)	1	1	2	1/2	1/2
η	1	2	2	0	−1/2
ζ	1	1	1	0	1
$(\psi_1^0,\psi_1^-)_R$	1	1	2	−1/2	2
$(\psi_2^+,\psi_2^0)_R$	1	1	2	1/2	1
χ_R^+	1	1	1	1	−3/2
χ_R^-	1	1	1	−1	−3/2
χ_{1R}^0	1	1	1	0	−1/2
χ_{2R}^0	1	1	1	0	−5/2
σ	1	1	1	0	3

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¶C. Kownacki, E. Ma, N. Pollard, OP, M. Zakeri, 1706.xxxx

Symmetry breaking, Mass Generation, and Flavour Changing Neutral Currents

- $\langle \phi_R^0 \rangle = 0$, $\langle \eta_2^0 \rangle = 0$ and conserve S+T$_{3R}$
- All exotic fermions have half integer charges under S+T$_{3R}$
- Particle content and charge assignments result in additional unbroken Z_2 symmetry, under which exotic ferminons are odd and others are even
- S+T$_{3R}$ is broken to S' by $\langle \sigma \rangle \neq 0$ and gives masses to exotic fermions
- S' charges for exotic fermions are different from S+T$_{3R}$ charges
- Presence of ζ induces $\zeta^3\sigma^*$ and $\chi^0_{1R}\chi^0_{1R}\zeta$ breakes S' further to Z_3

Particle content of proposed model under $(T_{3R} + S) \times Z_2$

particles	gauge $T_{3R} + S$	global S'	Z_3	Z_2
u, d, ν, l	0	0	1	+
$(\phi_L^+, \phi_L^0), (\eta_2^+, \eta_2^0), \phi_R^0$	0	0	1	+
n, ϕ_R^+, ζ	1	1	ω	+
$h, (\eta_1^0, \eta_1^-)$	-1	-1	ω^2	+
ψ_{2R}^+, χ_R^+	$3/2, -3/2$	0	1	−
ψ_{1R}^-, χ_R^-	$3/2, -3/2$	0	1	−
ψ_{1R}^0, ψ_{2R}^0	$5/2, 1/2$	$1, -1$	ω, ω^2	−
χ_{1R}^0, χ_{2R}^0	$-1/2, -5/2$	$1, -1$	ω, ω^2	−
σ	3	0	1	+

Conclusions

- (Alternative, Dark)Left-Right Models have no tree level FCNC
- Generate naturally small neutrino masses (Seesaw I/II/III/Double)
- Rich phenomenology accessable at LHC
- Different variations are possible
- Natural Dark Matter candidates due to residual symmetry
- 2 layers of DM stabilized by Z_3 and Z_2 in case of Gauged DLRM