Model with $L_\mu - L_\tau$ symmetry and Majorana Neutrinos

David Suárez

SILAFAE 2024

December 3, 2024

Overview

1. Motivation
2. Model

Standard Model of Elementary Particles

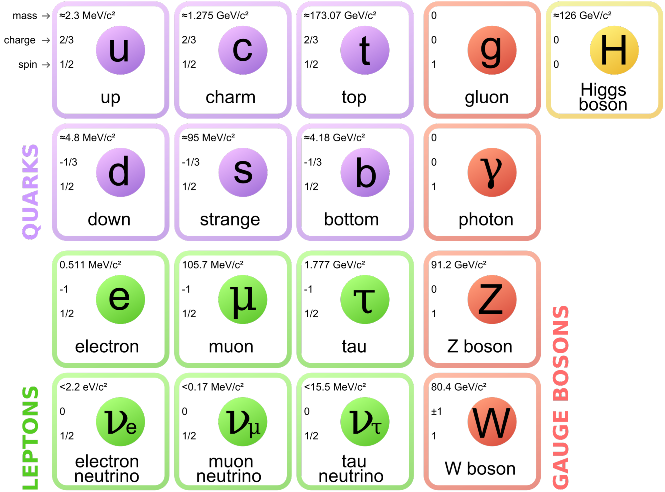


Figure:

Motivation

t
top
d
down
c
charm
s
strange
u
up
b
bottom
γ
photon
g
gluon
H
Higgs boson
τ
tau
W
W boson
Z
Z boson
ν_e
electron neutrino
μ
muon
ν_μ
muon neutrino
e
electron
ν_τ
tau neutrino

Z'
dark photon

Field Content

Particles	Spin	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$	$U(1)'$
ℓ_e	1/2	1	2	-1/2	0
ℓ_μ	1/2	1	2	-1/2	$+x$
ℓ_τ	1/2	1	2	-1/2	$-x$
H	0	1	2	+1/2	0
N_e	1/2	1	1	0	$-\frac{x}{2}$
N_μ	1/2	1	1	0	$+\frac{x}{2}$
N_τ	1/2	1	1	0	$-\frac{x}{2}$
N_ρ	1/2	1	1	0	$+\frac{x}{2}$
η_μ	0	1	2	+1/2	$+\frac{x}{2}$
η_τ	0	1	2	+1/2	$-\frac{x}{2}$
S	0	1	1	0	$+x$
σ	0	1	1	0	$+\frac{x}{2}$

Scalar Potential

$$
\begin{aligned}
V(H,\eta_\mu.\eta_\tau,\sigma) =& -\mu_H^2|H|^2+\mu_{\eta_{\tau,\mu}}^2|\eta_{\tau,\mu}|^2-\mu_S^2|S|^2-\mu_\sigma^2|\sigma|^2+\lambda_1|H|^4+\lambda_2|\eta|^4+\lambda_3|S|^4\\
&+\lambda_3'|\sigma|^4+\lambda_{S\sigma}|S|^2|\sigma|^2+\lambda_{12}|H|^2|\eta_{\tau,\mu}|^2+\lambda_{12}'|H^\dagger\eta_{\tau,\mu}|^2+\lambda_{13}|H|^2|S|^2\\
&+\lambda_{13}'|H|^2|\sigma|^2+\lambda_{23}|\eta_{\tau,\mu}|^2|S|^2+\lambda_{23}'|\eta_{\tau,\mu}|^2|\sigma|^2+\frac{\lambda_5}{2}\left(H^\dagger\eta_\mu H^\dagger\eta_\tau+\text{h.c}\right)\\
&+\mu_{S\sigma}\left(S(\sigma^*)^2+\text{h.c}\right)+\mu_{H\eta_\tau\sigma}\left(H^\dagger\eta_\tau\sigma+\text{h.c}\right)+\mu_{H\eta_\mu\sigma}\left(H^\dagger\eta_\mu\sigma^*+\text{h.c}\right)\\
&+\lambda_{H\eta_\mu S\sigma}\left(H^\dagger\eta_\mu S^*\sigma+\text{h.c}\right)+\lambda_{\eta_\tau HS\sigma}\left(\eta_\tau^\dagger HS^*\sigma+\text{h.c}\right)\\
&+\lambda_{\eta_\mu\eta_\tau S}\left(\eta_\mu\eta_\tau^\dagger S^*+\eta_\tau\eta_\mu^\dagger S\right)+\frac{\lambda_5}{2}\left(H^\dagger\eta_\mu H^\dagger\eta_\tau+\text{h.c}\right)\\
&+\mu_{S\sigma}\left(S(\sigma^*)^2+\text{h.c}\right)+\mu_{H\eta_\tau\sigma}\left(H^\dagger\eta_\tau\sigma+\text{h.c}\right)+\mu_{H\eta_\mu\sigma}\left(H^\dagger\eta_\mu\sigma^*+\text{h.c}\right)\\
&+\lambda_{H\eta_\mu S\sigma}\left(H^\dagger\eta_\mu S^*\sigma+\text{h.c}\right)+\lambda_{\eta_\tau HS\sigma}\left(\eta_\tau^\dagger HS^*\sigma+\text{h.c}\right)\\
&+\lambda_{\eta_\mu\eta_\tau S}\left(\eta_\mu\eta_\tau^\dagger S^*+\eta_\tau\eta_\mu^\dagger S\right)\ .
\end{aligned}
$$

Scalar Fields

$$
\begin{aligned}
H &= \begin{pmatrix} H^{+} \\ \frac{1}{\sqrt{2}}\left(v + h + iA\right) \end{pmatrix}, \\
\eta_{\mu,\tau} &= \begin{pmatrix} \eta^{+}_{\mu,\tau} \\ \frac{1}{\sqrt{2}}\left(\eta^{R}_{\mu,\tau} + i\eta^{I}_{\mu,\tau}\right) \end{pmatrix}, \\
S &= \frac{1}{\sqrt{2}}\left(v_S + s^R + is^I\right) \\
\sigma &= \frac{1}{\sqrt{2}}\left(v_\sigma + \sigma^R + i\sigma^I\right) \; . \; .
\end{aligned} \tag{1}
$$

Scalar Fields that acquire VEV

The mass matrix for scalars that acquire VEV:

$$m_h^2 = \begin{pmatrix} -\mu_H^2 + \frac{1}{2}\lambda_{13} v_s^2 - \frac{3\lambda_1 v^2}{2} & \lambda_{13} v v_s \\ \lambda_{13} v v_s & -\mu_s^2 + \frac{3}{2}\lambda_3 v_s^2 + \frac{\lambda_{13} v^2}{2} \end{pmatrix}$$

that is diagonalized by a unitary transformation $Z_H m_h^2 Z_H^T = m_{h,\text{diag}}^2$, such that:

$$\begin{pmatrix} h_0 \\ S^0 \end{pmatrix} = Z_H \begin{pmatrix} h_1 \\ h_2 \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} h_1 \\ h_2 \end{pmatrix}$$

Lagrangian for Right-Handed Neutrinos

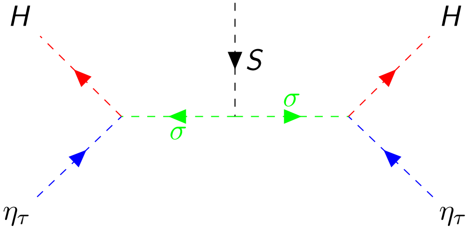
$$
\begin{aligned}
-\mathcal{L}_N &= Y_{ee}\overline{\ell}_e\tilde{\eta}_\tau N_e + Y_{e\mu}\overline{\ell}_e\tilde{\eta}_\mu N_\mu + Y_{e\tau}\overline{\ell}_e\tilde{\eta}_\tau N_\tau \\
&+ Y_{e\rho}\overline{\ell}_e\tilde{\eta}_\mu N_\rho + Y_{\mu\mu}\overline{\ell}_\mu\tilde{\eta}_\tau N_\mu + Y_{\mu\rho}\overline{\ell}_\mu\tilde{\eta}_\tau N_\rho \\
&+ Y_{\tau\tau}\overline{\ell}_\tau\tilde{\eta}_\mu N_\tau + Y_{\tau e}\overline{\ell}_\tau\tilde{\eta}_\mu N_e + Y_{\tau\mu}\overline{\ell}_\tau\tilde{\eta}_\tau N_\mu \\
&+ Y_{\tau\rho}\overline{\ell}_\tau\tilde{\eta}_\tau N_\rho + \frac{1}{2}h_{ee}\overline{N_e^c}N_e S + \frac{1}{2}h_{\mu\mu}\overline{N_\mu^c}N_\mu S^* \\
&+ \frac{1}{2}h_{\tau\tau}\overline{N_\tau^c}N_\tau S + \frac{1}{2}h_{\rho\rho}\overline{N_\rho^c}N_\rho S^* \\
&+ \frac{1}{2}h_{e\tau}\left(\overline{N_e^c}N_\tau + \overline{N_\tau^c}N_e\right) S + \frac{1}{2}h_{\rho\mu}\left(\overline{N_\rho^c}N_\mu + \overline{N_\mu^c}N_\rho\right) S^* \\
&+ \frac{1}{2}M_{\rho\tau}\left(\overline{N_\rho^c}N_\tau + \overline{N_\tau^c}N_\rho\right) + \frac{1}{2}M_{e\rho}\left(\overline{N_e^c}N_\rho + \overline{N_\rho^c}N_e\right) \\
&+ \frac{1}{2}M_{\mu\tau}\left(\overline{N_\mu^c}N_\tau + \overline{N_\tau^c}N_\mu\right) + \frac{1}{2}M_{e\mu}\left(\overline{N_e^c}N_\mu + \overline{N_\mu^c}N_e\right) + \text{h.c.}
\end{aligned}
$$

Mass Matrix for Right-handed Neutrinos

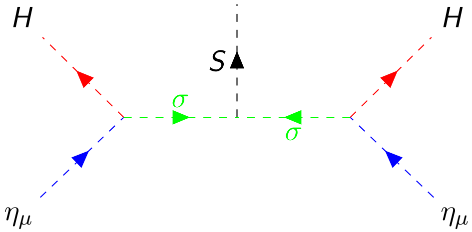
The mass matrix M_N:

$$M_N = \begin{pmatrix} h_{ee}\frac{v_S}{\sqrt{2}} & M_{e\mu} & h_{e\tau}\frac{v_S}{\sqrt{2}} & M_{e\rho} \\ M_{e\mu} & h_{\mu\mu}\frac{v_S}{\sqrt{2}} & M_{\mu\tau} & h_{\mu\rho}\frac{v_S}{\sqrt{2}} \\ h_{e\tau}\frac{v_S}{\sqrt{2}} & M_{\mu\tau} & h_{\tau\tau}\frac{v_S}{\sqrt{2}} & M_{\rho\tau} \\ M_{e\rho} & h_{\mu\rho}\frac{v_S}{\sqrt{2}} & M_{\rho\tau} & h_{\rho\rho}\frac{v_S}{\sqrt{2}} \end{pmatrix}$$

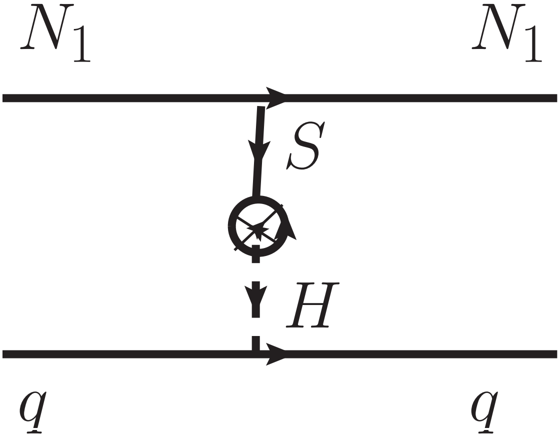
Effective λ_5 coupling I



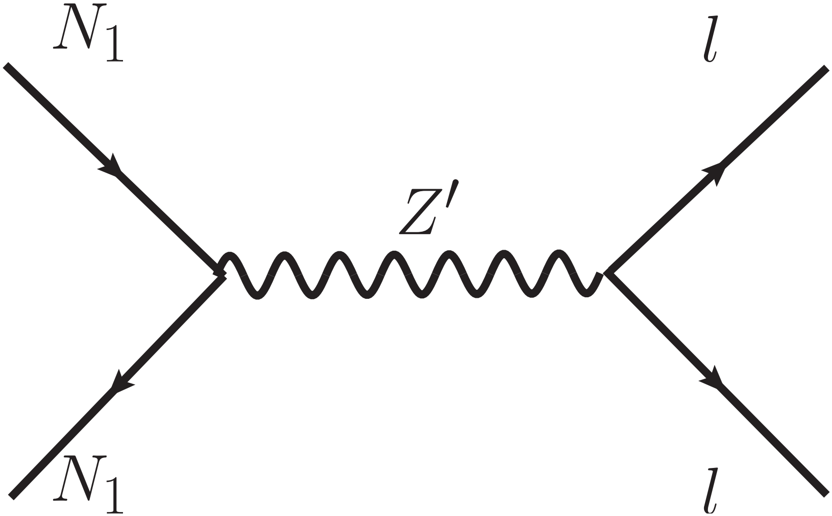
Effective λ_5 coupling II



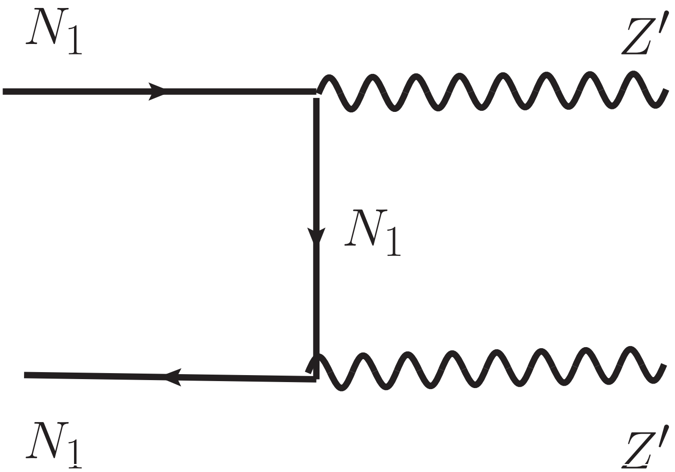
Direct Detection



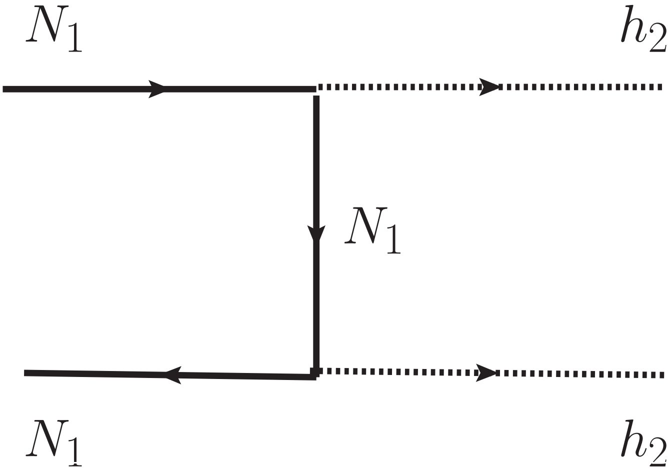
Dark Matter Relic Abundance



Dark Matter Relic Abundance II



Dark Matter Relic Abundance III



Thank you!