Anomaly-free abelian gauge symmetries with neutrino mass models

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Motivation

One of the most intriguing problems of the SM is the masslessness of neutrinos, which is contradicted by the experimental evidence. It has been established that neutrinos have a small mass, but different from zero, therefore the first experimental proof of new physics beyond the SM has been achieved. We propose a model to obtain the small neutrino masses by extending the visible content of the Standard Model (SM) with a hidden sector composed of two scalars singlet S and at least two right-handed singlet neutrinos ($\nu_R 1, \nu_R 2$). These right-handed neutrinos are charged under a new symmetry U$(1)_X$. In addition, it is necessary to add a heavy scalar doublet to play the role of messenger between the visible sector (SM) and the "hidden" sector.

The Model

By extending the visible content of the SM (the standard model of quarks and leptons is free of anomalies) with an active abelian gauge symmetry $U(1)_X$, anomalies automatically appear in the model. This implies that these anomalies in gauge symmetries make the theory physically inconsistent. This is because when we introduce a single helicity fermion (right-handed or left-handed) the quantum field theory goes out of whack. If we want to build a consistent theory, then we must make sure that all anomalies must be suppressed.

In our case, it is intended to generalize for an indeterminate number of chiral fermions, the local gauge symmetry added to the SM consists of at least (ν_{R_1}, ν_{R_2}) and a scalar singlet S which spontaneously breaks the symmetry. Extending the SM with a new abelian symmetry automatically violates the Lorentz invariance, therefore the following conditions must be imposed to avoid anomalies on the model [1]

$$\sum_{\alpha=1}^{N'} n_\alpha + 3m = 0\,, \tag{1}$$

$$\sum_{\alpha=1}^{N'} n_\alpha^3 + 3m^3 = 0\,, \tag{2}$$

where, n_α is defined as the charge of the chiral fermions under the new symmetry and $3m$ the sum of the charges of the SM and $m \equiv e + 2L$. If the SM is extended with an additional dark $U(1)_D$ gauge symmetry (under which it is uncharged), and N right-handed chiral fields singlets under the SM group, the $U(1)_D$ is not anomalous if the Diophantine equations are fulfilled

$$\sum_{\alpha=1}^{N} n'_\alpha = 0\,, \qquad \sum_{\alpha=1}^{N} n'^3_\alpha = 0\,. \tag{3}$$

To solve these equations we must follow the following steps

Step 1:
- Chiral set without anomalies with $5 \leq n \leq 12$ chiral fermions.

Step 2:
- The solutions obtained by https://github.com/restrepo/anomaly/raw/main/solutions.json.gz.

Step 3:
- Constraints from the tree-level model are implemented.

Step 4:
- The solutions where all the fermions remain with mass are filtered.

Dark Sector

Let the Dirac fermion ψ with coupling to H given by $fH\bar{\psi}\psi$. Its coupling to the gauge boson $U(1)_D$ Z_D is assumed to be $g_D Z_D^\mu \psi\gamma_\mu\psi$. Let Z_D be lighter than ψ, then the relic abundance of ψ is determined by its annihilation to Z_D, as shown in figure (1) [2].

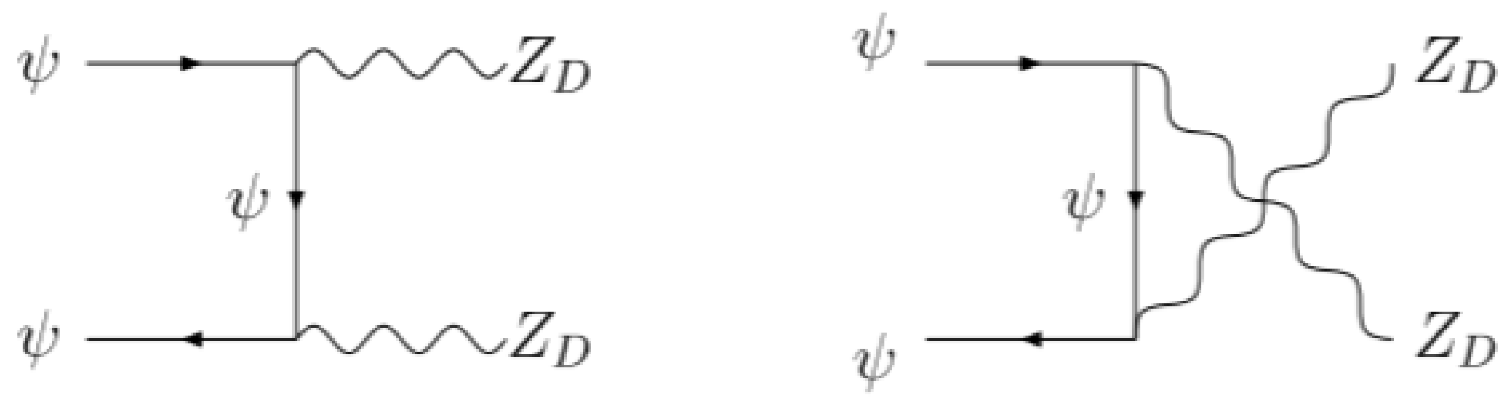

Figura 1. Annihilation of $\psi\psi \rightarrow Z_D Z_D$

This cross section by relative velocity is given by

$$\sigma v_{\rm rel} = \frac{g_D^4}{16\pi m_\psi^2}(1 - M_D^2/m_\psi^2)^{3/2}(1 - M_D^2/2m_\psi^2)^{-2} \tag{4}$$

Setting the value of $\sigma v_{\rm rel} = 5{,}089 \times 10^{-9}[GeV]$ and $g_D = 0{,}86$ relic abundance can be obtained, as shown in figure (2).

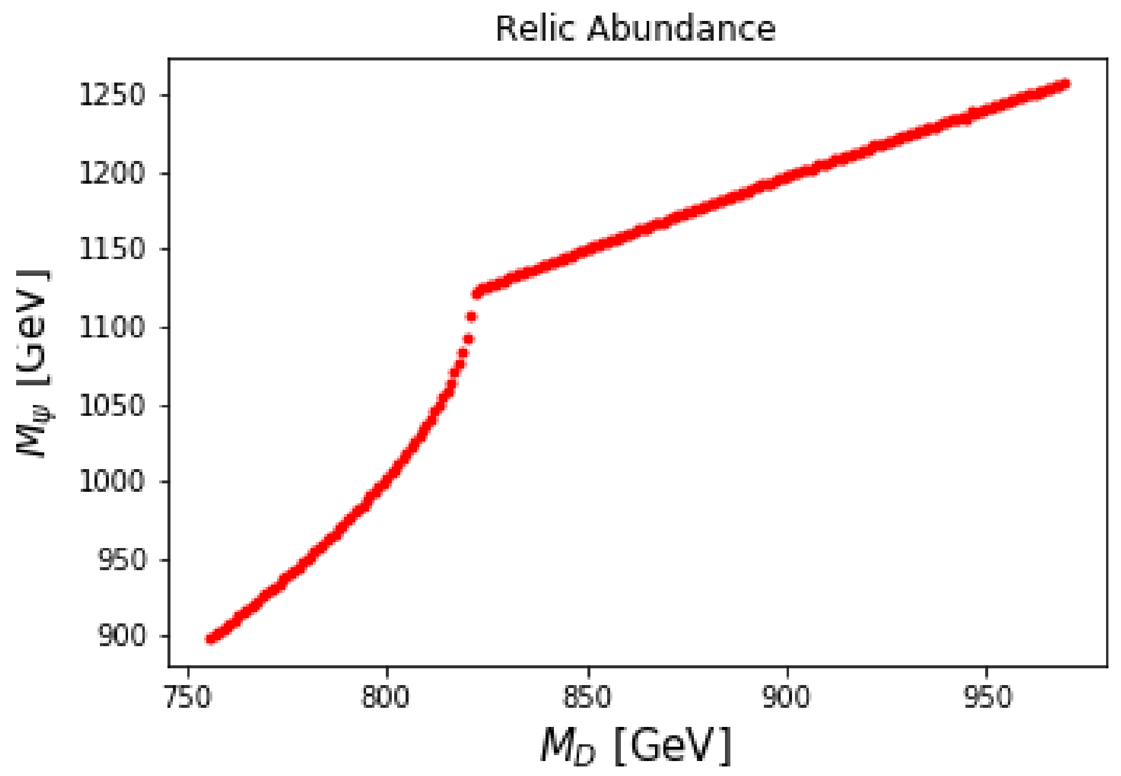

Figura 2. Relic Abundance.

Conclusion

Studies on tree-level Dirac neutrino masses have typically focused on finding specific anomaly-free solutions for active or dark symmetry. In this work a set of anomaly-free solutions has been presented for the general problem of the generation of Dirac neutrino masses at the tree level with chiral singlet fermions.

Bibliography

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[2] E. Ma, "Linkage of Dirac neutrinos to dark U(1) gauge symmetry" (2021) arXiv:2101.12138v2 [hep-ph].