Introduction

Target:

Build a model which relates Diracness of neutrinos with the stability of a potential scalar dark matter candidate.

- Motivation:
  - Majorana nature of neutrinos not experimentally determined (yet).
  - There are many more models with Majorana neutrinos than Dirac ones.
  - Dark matter problem still opened.

The model

- Standard Model gauge group.

- New particles (singlets under gauge group):
  - Fermion N with the two helicities.
  - Real scalar χ with non-vanishing vev.
  - Real scalar η.
  - Complex scalar ζ.

- Global symmetry under $Z4 \otimes Z2$.

The model

- The transformation rules of the fields under Z4⊗Z2 have to be arranged in such a way that:
  - Neutrinos are Dirac particles.
  - Neutrino masses are small in a natural way.
  - One of the scalars must be stable to be a viable DM candidate

Neutrino Diracness

- Z4 is the symmetry which ensures Dirac nature of neutrinos.
- After SSB, scalars with vev will break all symetries under which they transform non-trivially. Therefore, Φ and χ must transform with the identity under Z4.
- Majorana terms must be forbidden at all orders. For example:

$$\bar{\nu}_R \nu_R^c \Phi^\dagger \Phi \chi$$

Smallness of neutrino masses

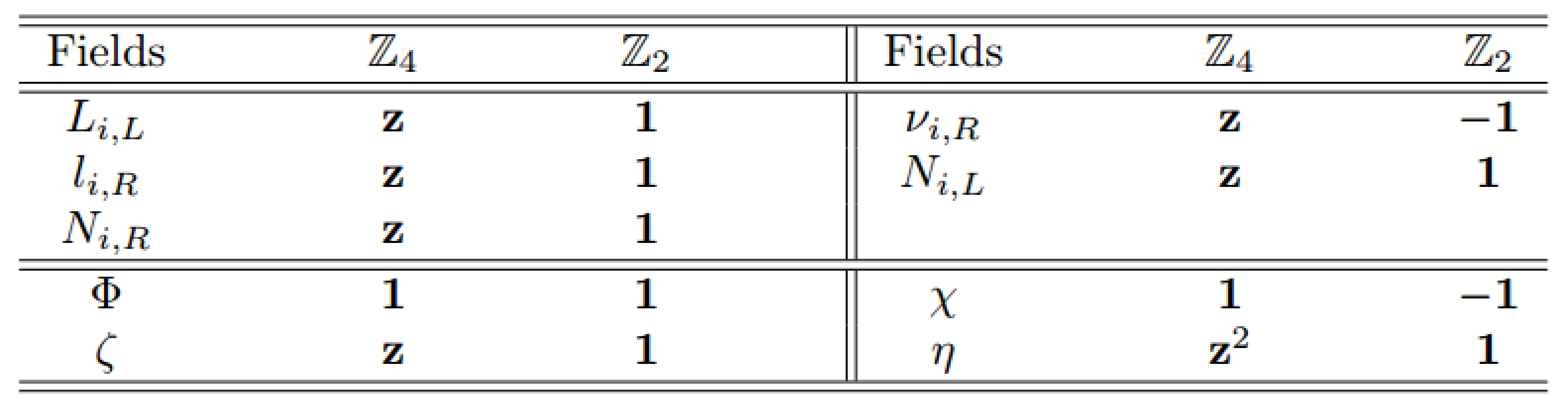
- Small neutrino masses can always be imposed by hand with small yukawa couplings.
- Seesaw mechanism is the most popular way of having a ‘natural’ (i.e. adimensional couplings of the same order) theory with small neutrino masses.
- Z2 symmetry role is to forbid the mass term between left and right neutrinos and therefore having a seesaw mass generation mechanism.

DM candidate

- We want the complex scalar ζ to be the DM particle.
- To be a viable DM candidate it must be stable and therefore interaction terms with fermions must be forbidden. *Z4* can do this.
- Pretty result: **The same symmetry responsible for having Dirac neutrinos ensures DM stability.**

The model

- Taking all these into account, the transformation rules are:



Fields	$\mathbb{Z}_4$	$\mathbb{Z}_2$	Fields	$\mathbb{Z}_4$	$\mathbb{Z}_2$
$L_{i,L}$	$\mathbf{z}$	1	$\nu_{i,R}$	$\mathbf{z}$	-1
$l_{i,R}$	$\mathbf{z}$	1	$N_{i,L}$	$\mathbf{z}$	1
$N_{i,R}$	$\mathbf{z}$	1			
Φ	1	1	χ	1	-1
ζ	$\mathbf{z}$	1	η	$\mathbf{z}^2$	1

- With these charges under Z4⊗Z2 the previous conditions are satisfied, i.e:
  - Neutrinos are Dirac particles (via Z4).
  - Seesaw mechanism for neutrino masses (via Z2).
  - Stable scalar: DM candidate (via Z4).

Neutrino masses

- After SSB, the mass lagrangian for neutral fermions can be written as:

$$\mathcal{L}_m = \begin{pmatrix} \bar{\nu}_L & \bar{N}_L \end{pmatrix} \begin{pmatrix} 0 & f\frac{v}{\sqrt{2}} \\ gu & M \end{pmatrix} \begin{pmatrix} \nu_R \\ N_R \end{pmatrix}$$

- Dirac seesaw. The perturbative diagonalization method gives:

$$M_\nu = \frac{uv}{\sqrt{2}} f M^{-1} g$$

- f, g and M are completely arbitrary 3x3 matrices. They can fit any neutrino data but explains nothing.

arxiv

Possible extensions

- One possibility is to change Z2 by a more complex symmetry, for example $\Delta(27)$.
- Three generations of each scalar with vev.
- Same main features than the original model (Dirac neutrinos, seesaw mechanism, DM candidate) with constraints in the couplings f, g and M that can explain CP violation parameters under certain assumptions.

arxiv

Conclusions

Construction of a model (arxiv) with naturally light Dirac neutrinos and a DM candidate. **The same symmetry Z4 that forbids Majorana terms even after SSB is the same that makes the scalar DM stable.**

Simple model which can be easily extended to correlate CP violation with the χ vev alignment: Z2→Δ(27) (arxiv)