PROCEEDINGS OF SCIENCE

SWSM phenomenology

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The superweak force is a minimal, anomaly-free U(1) extension of the standard model, designed to explain the origin of (i) neutrino masses and mixing matrix elements, (ii) dark matter, (iii) cosmic inflation, (iv) stabilization of the electroweak vacuum and (v) leptogenesis. In this contribution we discuss how the parameter space of the model is constrained by providing viable scenarios for the first four of this list.

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The standard model (SM) of elementary particle interactions has proved to describe the results of a plethora of measurements carried out both at low and at high characteristic energy scales. The agreement between theory and experiment is typically within 1 or 2 σ with very few exceptions of proven deviations from the SM [1]: (i) the *measured abundance of dark matter in the universe assuming it has particle origin*; (ii) the *non-vanishing neutrino masses*; (iii) the *observed matter–anti-matter asymmetry*, which however, clearly call for an extension of the SM. In addition to (i)–(iii), there are cosmological observations, such as (iv) the *late time accelerated expansion of the universe* and (v) inflation in the early universe that might find explanations in particle physics beyond the SM (BSM). Such a BSM extension is viable only if it respects (a) the high precision confirmations of the SM (b) and the lack of finding new particles beyond the Higgs boson by the collider experiments. The goal of the superweak (SW) extension of the SM is to find explanations to observations (i–v) without violating (a) and (b).

The physics of neutrinos must play a key role in the quest for the BSM theories as their non-vanishing mass implies that they must feel another force in addition to the weak force. An interaction with the Brout-Englert-Higgs (BEH) field requires the existence of right-handed neutrinos $\nu_{\rm R}^f$. The SWSM assumes such neutrinos existing in three families ($f = 1, 2$ and 3) just like the SM fermions. Such neutrinos must be sterile under the SM gauge interactions, and might have observable effects only if they couple to the charged fermions through a new force. Hence, the model also assumes the extension of the SM gauge group $G_{\rm SM} = {\rm SU}(3)_{\rm c} \otimes {\rm SU}(2)_{\rm L} \otimes {\rm U}(1)_Y$ by a new U(1) to $G = G_{\rm SM} \otimes {\rm U}(1)_z$. As such a new gauge interaction is not observed directly among the SM fermions, it is likely to be broken. Hence, the SWSM assumes the existence of a new complex scalar whose vacuum expectation value w breaks the new U(1). Such a scalar field also has the potential to stabilize the vacuum up to the Planck scale $m_{\rm P}$, which property is not shared by the SM where the scalar potential is unbounded from below at energy scales above $\simeq 10^{11}$ GeV. In the SWSM the new z charges belonging to the ${\rm U}(1)_z$ interaction are assigned such that gauge and gravity anomalies are absent.

Detailed definition of the SWSM was given in Ref. [2], while more comprehensive descriptions of the various new sectors were published in Ref. [3] discussing the scalar sector, in Ref. [4] detailing the gauge sector equations and in Refs. [5, 6] about the neutrino masses. Our goal in the present contribution is to present the current status of the phenomenology of the model with the *goal of constraining its parameter space such that it can fulfill its promises while respects the existing experimental constraints*.

The SWSM assumes a new complex scalar field whose ground state breaks the new ${\rm U}(1)_z$ symmetry spontaneously, hence predicts the existence of a new scalar particle. The new scalar resembles the singlet scalar extension of the SM with important extra features: (i) it couples to neutrinos, (ii) it interacts with all fermions via the new gauge boson Z' and also via mixing with the Higgs boson; (iii) its vacuum expectation value gives mass to the Z', which, in turn, mixes with the Z^0.

Careful analysis shows [3] that this new scalar S can stabilize the vacuum being either lighter than the Higgs boson, $M_S < M_H$, or heavier, $M_S > M_H$. In both cases we explored the exclusion limits provided by the LEP and LHC collider experiments. Here we present preliminary results for the still allowed parameter space in the plane of the scalar mixing angle θ_S versus the scalar mass M_S in Fig. 1 for the case of $M_S > M_H$. We also show the region of the parameter space where the

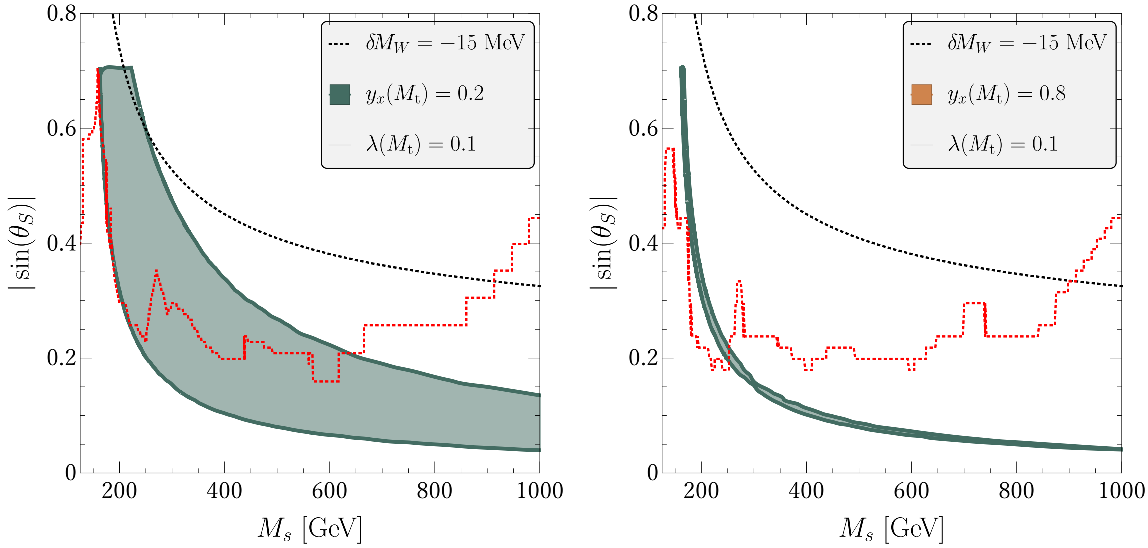

Figure 1: Parameter space of the scalar sector of the supeweak model preferred by the stability of the vacuum with perturbativity of the model up to m_P and allowed by experimental constraints provided by `HiggsBounds 5` [8] shown the limit provided by the PDG value of the W-mass.

presence of the second scalar stabilizes the vacuum up to m_P for two values of the Yukawa coupling of the heavy sterile neutrino, $y_x = 0.2$ (left) and 0.8 (right). Above 0.8 the region vanishes quickly with increasing y_x because the heavy neutrino drives the scalar coupling negative below m_P. These regions are most sensitive to the quartic coupling λ that mixes the two scalar fields in the potential energy function ($\lambda = 0.1$ in the figure). The details of this study are described in the contribution [7] where the exclusion region for the case of $M_S < M_H$ is also presented.

We have firm evidence that dark matter (DM) exists in the Universe. Here we assume that the DM has particle origin. The only chance to observe such a particle in the laboratory or in Nature if it interacts with the particles of known baryonic matter, which must be mediated by a field, called *portal*. In the SWSM the lightest sterile neutrino $\nu_{R,1}$ as DM candidate with a vector boson portal – as the Z' couples to all SM particles – is a natural scenario, studied in detail in Ref. [4].

The current DM abundance can be reached either by (i) the freeze-out or (ii) the freeze-in mechanism, and the SWSM supports both ways. Here we discuss only case (i), when the observed DM abundance can only be achieved by the resonant production mechanism, in which case the mass of the DM particle is approximately half of that of the portal particle, $M_{\nu_{R,1}} \equiv M_1 \simeq M_{Z'}/2$. Otherwise, the new gauge coupling is too large, O(10^{-3}), already excluded. We show the parameter space for the freeze-out scenario in Fig. 2. The dark matter particle is the lightest right-handed neutrino with mass M_1 in this plot. The required dark couplings g_z reproducing $\Omega_{\rm DM} = 0.265$ are plotted against the mass of the new gauge boson Z' for various values of the dark matter mass. The shaded regions of the parameter space are excluded by measurements discussed in Ref. [9].

We have studied the allowed parameter space of the superweak extension of the standard model of particle interactions via focusing on (i) the scalar sector of the model and (ii) the possible source of dark matter. We have found that the model provides viable phenomenology to solve these puzzles.

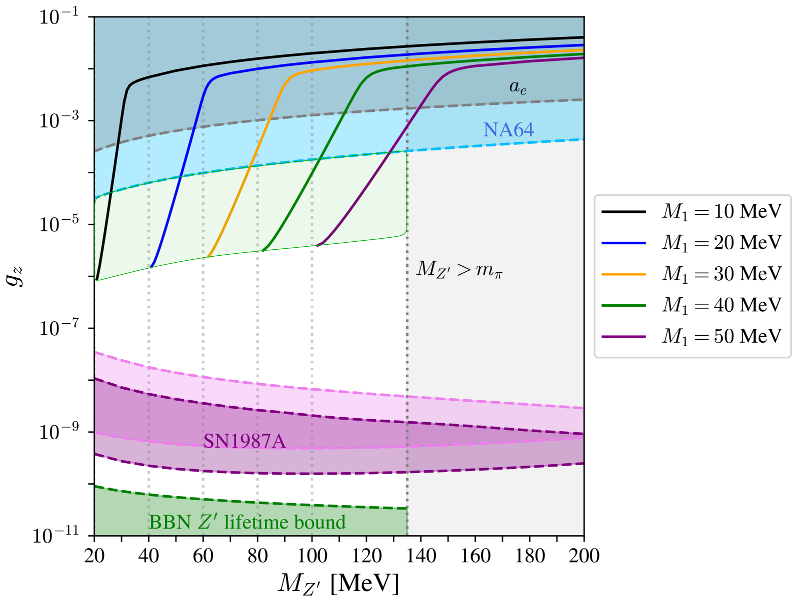

Figure 2: Parameter space for the freeze-out scenario of dark matter production in the supeweak model.

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