Searching For Fundamental Novel Physics in CDF-II W Boson Mass Anomaly

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Introduction

- The CDF-II collaboration's recent high-precision measurement of W boson mass, M_W^{CDF} = 80.4335 ± 0.0094 GeV [1], indicates 7σ deviation from the SM expectation $M_W = 80.354 \pm 0.007$ GeV.
- We investigate the possibility of the well-known canonical Scotogenic model, where dark matter particle running in the loop generates neutrino masses, to explain the CDF-II measurement.
- In our second work, we focused on $U(1)_{B-L}$ gauged SM extension. We demonstrate that B-L extended models can explain the revised best fit values for S, T , and U following the CDF II results.

Methodology

- dominant BSM effects can be written in terms of the three gauge boson self-energy parameters known as the oblique parameters S, T and U provided that the new physics mass scale is greater than the electroweak scale and that it contributes only through virtual loops to the electroweak precision observables.
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$$M_W = M_W^{\text{SM}} \left[1 - \frac{\alpha}{4(\cos^2\theta_w - \sin^2\theta_w)} (S - 1.55T - 1.24U) \right] \quad (1)$$

The recent values of these parameters from an analysis of precision electroweak data including the CDF-II new result of the W-mass:

$$S = 0.06 \pm 0.1,\ T = 0.11 \pm 0.12,\ U = 0.13 \pm 0.09. \quad (2)$$

with the correlation

$$\rho_{ST} = 0.90,\ \rho_{SU} = -0.59 \text{ and } \rho_{TU} = -0.85. \quad (3)$$

The Canonical Scotogenic Neutrino-Dark Matter Model[2]

Fields		$\mathbb{Z}_2$
L	$(1, 2, -\frac{1}{2})$	$+1$
ℓ	$(1, 1, -1)$	$+1$
Φ	$(1, 2, \frac{1}{2})$	$+1$
N	$(1, 1, 0)$	-1
η	$(1, 2, \frac{1}{2})$	-1

- Canonical scotogenic model is the simple extension of SM, proposed by Ma.

  The components of the $SU(2)_L$ doublet scalars are given by

$$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}, \qquad \eta = \begin{pmatrix} \eta^+ \\ \eta^0 \end{pmatrix}. \quad (4)$$

$$\langle \Phi \rangle = \frac{v_\Phi}{\sqrt{2}}, \qquad \langle \eta \rangle = 0. \quad (5)$$

- The BSM invariant Yukawa Lagrangian relevant for neutrino mass generation is given as

$$-\mathcal{L}_Y = Y^N_{\alpha\beta} \overline{N}_\alpha \eta L_\beta + \frac{1}{2} \overline{N^c}_\alpha M_{\alpha\beta} N_\beta + hc, \quad (6)$$

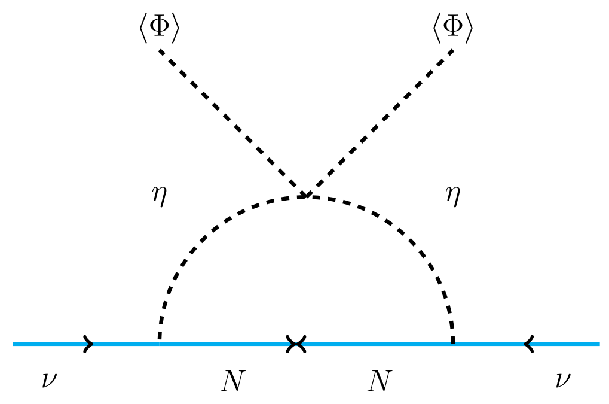

Figure 1: One loop neutrino mass in the minimal Scotogenic model, where $\eta_0 = (\eta_R, \eta_I)$

In the canonical Scotogenic model, the presence of the dark scalar η leads to corrections to gauge boson two-point functions through loop diagrams as shown in

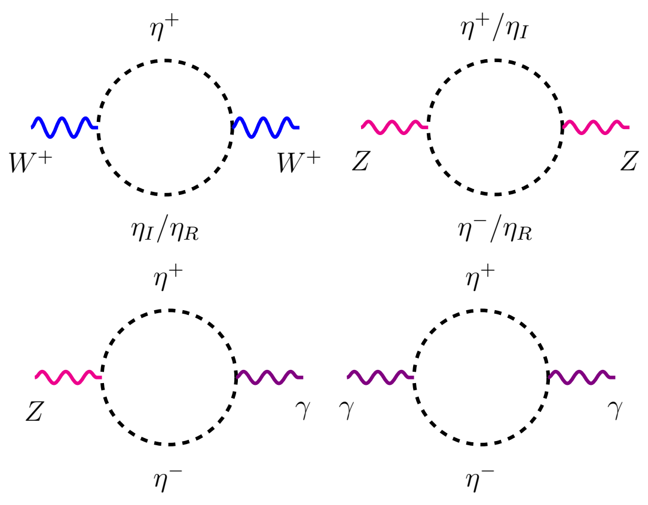

Figure 2: One loop polarization diagrams that contribute to the oblique parameters S, T, U.

- We ensure that the scalar potential is bounded from below, by imposing the vacuum stability constraints given in
- We ensure the perturbativity of the couplings, i.e. the scalar quartic couplings are taken to be less than $\mathcal{O}(1)$.
- One of the key goals of the Scotogenic model is to provide an explanation for small neutrino masses. We guarantee this by demanding compatibility of allowed parameter range with the best-fit ranges of the neutrino oscillation parameters throughout our analysis.
- The constraints from neutrinoless double beta decay (for normal ordering) experiments as well as limits from cosmology and KATRIN experiments are imposed.
- Constraints from the lepton flavour violating (LFV) processes $\ell_\alpha \to \ell_\beta\gamma$ are imposed.

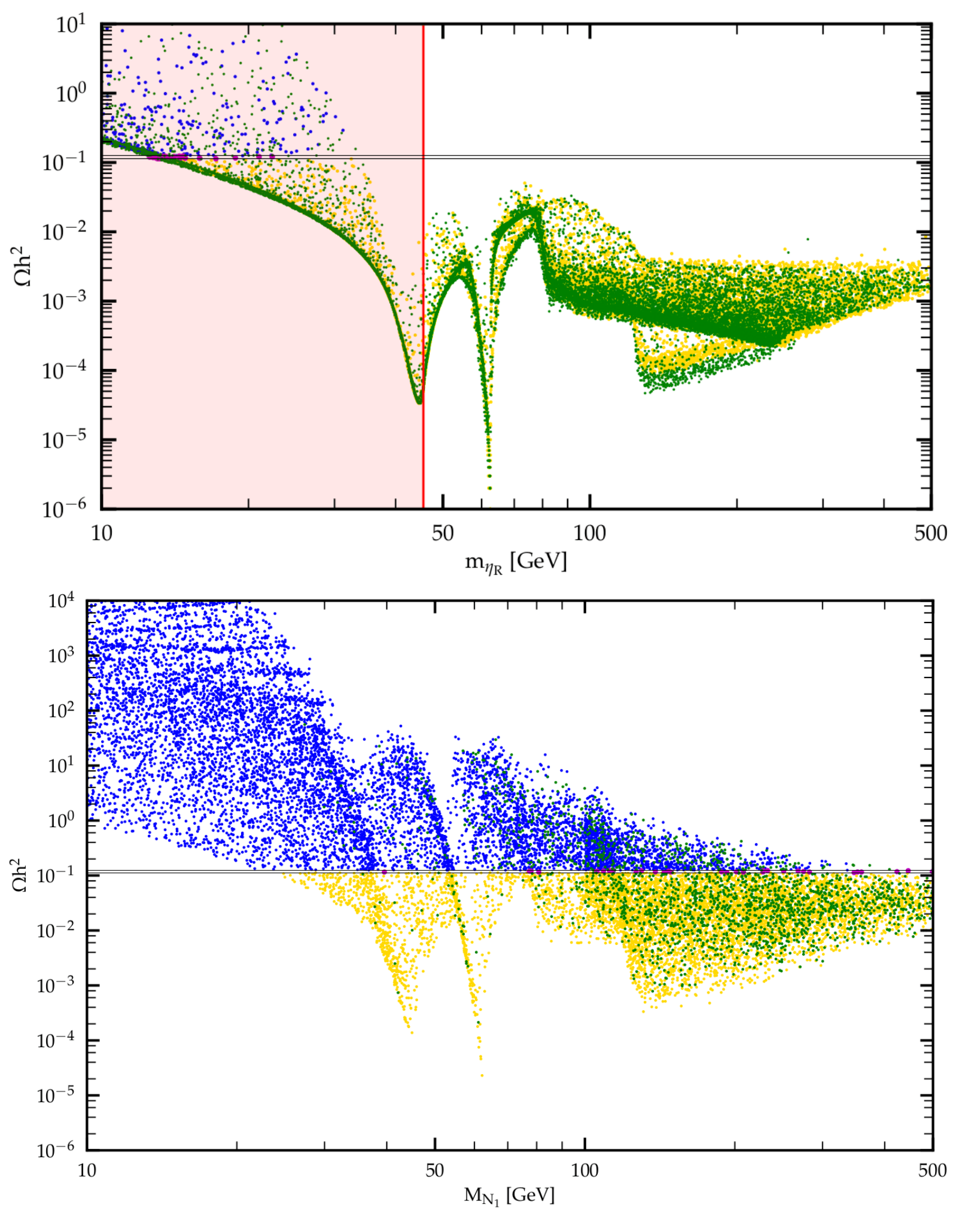

Figure 3: First graph represents the Relic density for the scalar dark matter candidate η_R for varying values of m_{η_R}. The second graph is for Relic density for the fermionic dark matter candidate N_1 as a funcion of mass M_{N_1}.

- We show that in the canonical Scotogenic model, the scalar dark matter is mostly ruled out due to relic, direct detection and LEP constraints and fermion dark matter has enough parameter space to simultaneously satisfy all the aforementioned constraints.

$B - L$ model in light of the CDF II result

Kinetic-Mixing and W mass:

- In this work we briefly discuss the possibility of having kinetic mixing between two field strength tensors corresponding to $U(1)_Y$ and $U(1)_{B-L}$. We investigate in detail whether or not addressing simply the impacts of kinetic mixing at the tree level may resolve the W mass anomaly.

$$\mathcal{L}_{\text{Kinetic}} = -\frac{1}{4} B^{\mu\nu} B_{\mu\nu} - \frac{1}{4} X^{\mu\nu} X_{\mu\nu} - \frac{\kappa}{2} B^{\mu\nu} X_{\mu\nu}, \quad (7)$$

- Taking the CDF II measured W mass, $M_W = 80.4335 \pm 0.0094$ GeV and using the PDG [3] values for other input parameters, $\sin^2\theta_w = 0.23121 \pm 0.00004$, $G_f = 1.1663787(6) \times 10^{-5}$ (GeV)$^{-2}$, we calculated weak couplings that is consistent with CDF-II meaured W mass and then calculated the Z mass. With this, the central value of the theoretically computed Z mass is given as

$$M_Z|_{\kappa=0} = 91.7345 \text{ GeV}, \quad (8)$$

  which is ofcourse larger than the experimental value of $M_Z = 91.1876$ GeV.
- As a result, the new physics contribution from kinetic mixing κ can reduce the Z mass to the experimental value.

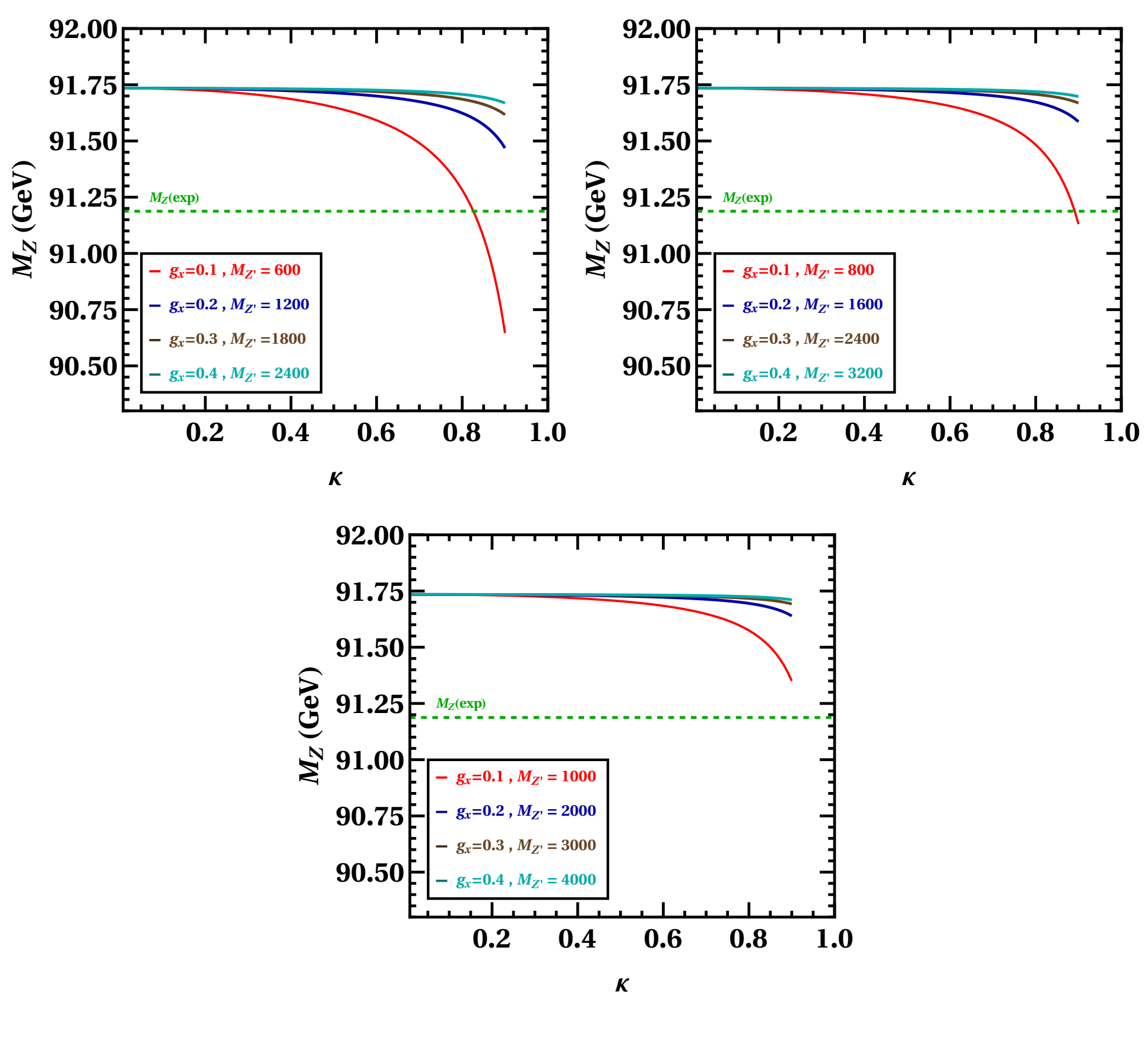

Figure 4: Z mass versus kinetic mixing κ. The coloured lines in each panel correspond to different g_x and M_Z values while keeping the ratio $\frac{M_{Z'}}{g_x}$ constant.

Chiral B-L Model:

We proposed the extension of the minimal $B - L$ model and used these oblique parameters to study the W mass anomaly.

Fields	($SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)_{B-L}$)
L_L	$(1, 2, -1/2, -1)$
Q_L	$(3, 2, 1/6, 1/3)$
e_R	$(1, 1, -1, -1)$
u_R	$(3, 1, 2/3, 1/3)$
d_R	$(3, 1, -1/3, 1/3)$
ν_R^1	$(1, 1, 0, 5)$
$\nu_R^{2,3}$	$(1, 1, 0, -4)$
Φ	$(1, 2, 1/2, 0)$
φ	$(1, 2, 1/2, -3)$
σ	$(1, 1, 0, 3)$
χ_d	$(1, 1, 0, 1/2)$

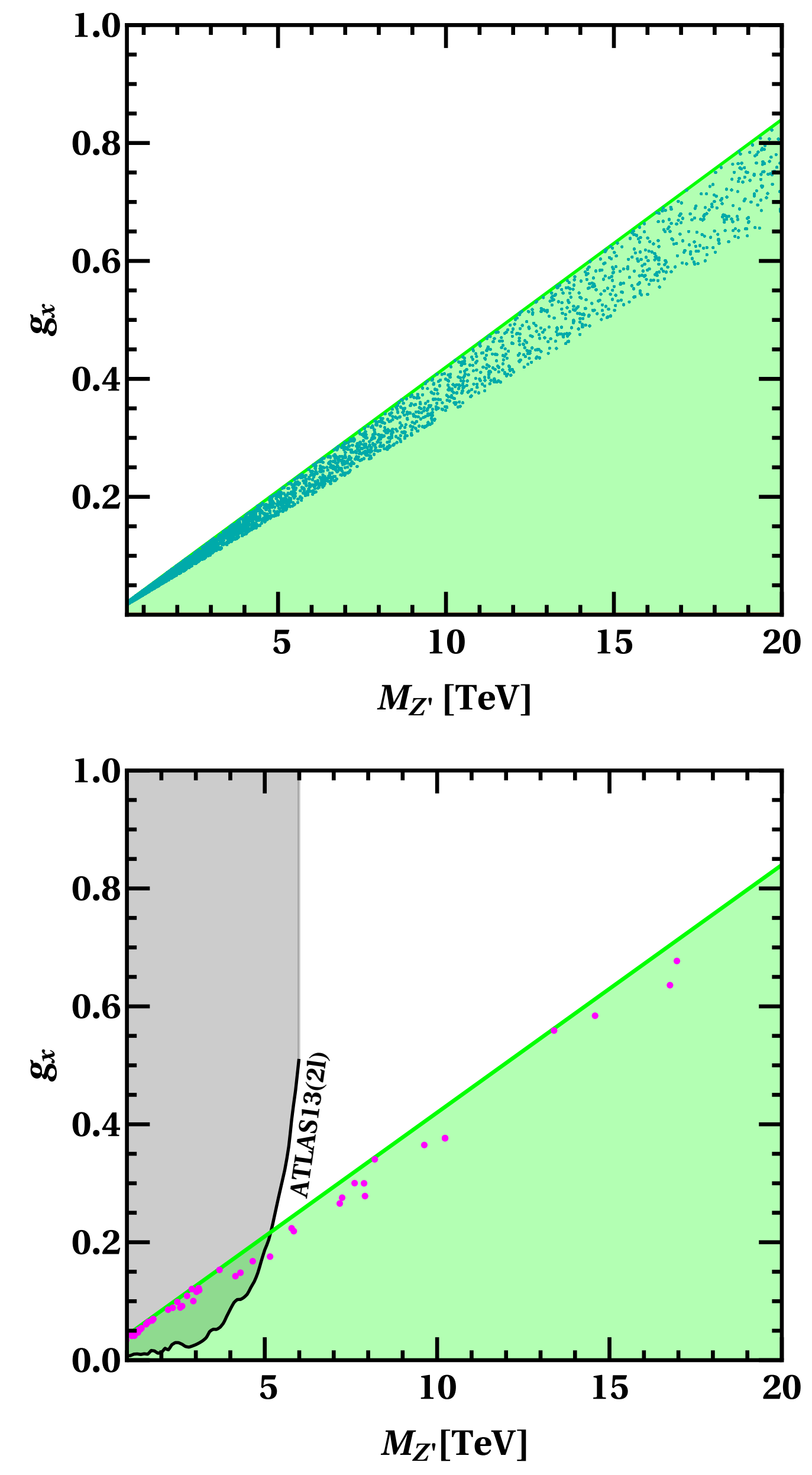

Figure 5: In first graph, for chiral $B - L$ model, we showed the space permitted by the new oblique parameters (S, T, U) after CDF-II results (3σ) in green colour. Dark Cyan points are consistent with CDF-II, W mass measurement. In second graph we showed allowed points in magenta after imposing all the constraints.

Summary of Results

1. We investigate the possibility of the well-known canonical Scotogenic model, where dark matterparticle running in the loop generates neutrino masses, to explain the CDF-II measurement. For both scalar and fermionic dark matter possibilities, we simultaneously examine the various constraints. We show that the viable parameter space of doublet scalar carrying a dark parity charge is nearly ruled out by the new CDF-II measurement while the fermionic dark matter in the canonical Scotogenic model can simultaneously explain all the aforementioned issues.
2. We demonstrate that $B - L$ extended models can explain the revised best fit values for S, T , and U following the CDF II results. We studied the parameter space of models with and without mixing between neutral gauge bosons. We also reviewed the dark matter constraints and demonstrated that there are parameter space which is compatible with current W boson mass, relic abundance, and direct detection experiments.

References

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