Explain the $W$-boson mass anomaly in the context of Supersymmetric $U(1)_{Y'} \otimes U(1)_{B-L}$ with three identical neutrinos

M. C. Rodriguez
Grupo de Física Teórica e Matemática Física
Departamento de Física
Universidade Federal Rural do Rio de Janeiro - UFRRJ
BR 465 Km 7, 23890-000
Seropédica, RJ, Brazil,
email: marcosrodriguez@ufrrj.br

Abstract

We will present within the context of the supersymmetric version with $U(1)_{Y'} \otimes U(1)_{B-L}$ gauge symmetry, where $Y'$ is a new charge and $B$ and $L$ are the usual baryonic and leptonic numbers, an explanation for the new data on the $W$-boson mass recently presented by the CDF collaboration.

12.60.Jy 12.60.Cn

1 Introduction

The CDF Collaboration at Fermilab presented its new precision measurement of the $W$-boson mass [1]

$$(M_W)_{CDF} = (80.4335 \pm 0.0094) \text{ GeV}, \quad (1)$$

it was shown recently this measurement can be explained in the context of the models MRSSM [2] and the MSUSY331 [3]. The mechanism in those models is to introduce a new scalar field and it is not necessary to generate mass for the usual fermions therefore the vacuum expectation value (vev) of this new scalar field can be around 10 GeV

Some years ago, it was proposed a model in which $U(1)_{B-L}$ is not just a new factor added to the Standard Model gauge symmetry but $U(1)_{Y}$ is substituted by $U(1)_{Y'} \otimes U(1)_{B-L}$ and the breaking $U(1)_{Y'} \otimes U(1)_{B-L} \rightarrow U(1)_{Y}$ occurs at the TeV scale. Moreover, the number of right-handed neutrinos, $N_{iR}$, and their $B-L$ (or $Y'$) quantum numbers are free parameters,
but the cancellation of the cubic and the linear anomalies implies that at least three right-handed neutrinos must be added to the matter representation content. Explicit solutions for the $B - L$ (or $Y'$) parameters show that at least two types of model arise: i) the model with three right-handed neutrinos having $B - L = -1$ (known as three identical neutrinos); ii) the model with two right-handed neutrinos having $B - L = -4$ and the third one having $B - L = 5$ (known as three non-identical neutrinos) [4].

The Supersymmetric $U(1)_{Y'} \otimes U(1)_{B-L}$ with three identical neutrinos was presented at [5], where we present ourselves in addition to the particle content, we present the entire Lagrangian of the model. In this article, it was considered that no sneutrinos\(^1\), both left-handed, $\tilde{\nu}_{iL}$, and right-handed, $\tilde{N}_{iR}$, acquire vev and let’s represent them as $v^L_i$ and $v^R_i$ respectively. In this article we will relax this hypothesis and show that with this we can explain the new CDF data about $W$-boson mass.

We calculate the mass of gauge bosons in the usual way and in our model the contributions are given by

$$
(D_m H_1)\dagger (D^m H_1) + (D_m H_2)\dagger (D^m H_2) + (D_m \tilde{L}_{iL})\dagger (D^m \tilde{L}_{iL}) + (D_m \tilde{N}_{iL})\dagger (D^m \tilde{N}_{iL}) \\
+ (D_m \phi_1)\dagger (D^m \phi_1) + (D_m \phi_2)\dagger (D^m \phi_2).
$$

(2)

The $W$-boson mass is given by the following expression

$$
M^2_W = \frac{g^2}{4} \left[ v_1^2 + v_2^2 + \sum_{i=1}^{3} (v^L_i)^2 \right],
$$

(3)

and as expected it has no dependency on $v^R_i$, this vev will only contribute to the masses of neutral bosons, fermions and scalars and we hope to present our results for these cases soon as possible. We can rewrite this equation by defining the $\beta$-parameter, as in MSSM, plus a new set of parameters $\Xi_i$, for each vev of the left-handed sneutrinos, as follows

$$
\tan \beta = \frac{v_1}{v_2}, \\
\tan \Xi_i = \frac{v^L_i}{v_2},
$$

(4)

\(^1\)They are the superpartner of neutrinos.
and Eq.(3) can be rewritten as follows

$$M_{W}^{2} = \frac{g^{2}}{4} v_{2}^{2} \left[ 1 + \tan^{2} \beta + \sum_{i=1}^{3} \tan^{2} \Xi_{i} \right] . \quad (5)$$

To facilitate our numerical analysis, we break it down into the following two approximations

1. $v_{L}^{1} = v_{L}^{2} = 0$ and $v_{L}^{2} \neq 0$;

2. $v_{L}^{1} = v_{L}^{2} = v_{L}^{2} = v$.

we will now present our results separately for each of these approximations.

2 First Approximation

In this case, we have $\Xi_{1} = \Xi_{2} = 0$ and to simplify everything let’s adopt $\Xi_{3} = \Xi$. In this way, we can rewrite the $W$-boson mass succinctly as given by

$$M_{W}^{2} = \frac{g^{2}}{4} v_{2}^{2} \left[ 1 + \tan^{2} \beta + \tan^{2} \Xi \right] . \quad (6)$$

First, we fix the value of the $\beta$-parameter, and in this case we present two plots for the case where $\beta = (\pi/4)$ rad. Where in the first plot we made the $\Xi$-parameter vary from 0 rad to $(\pi/3)$ rad, see Fig.(1), note that if $v \sim \mathcal{O}(100)$ GeV, we can explain the new data from the CDF. In the next we consider $(\pi/3) \leq \Xi \leq (88 \pi)/180$ rad, see Fig.(2), but in this case we can accommodate the CDF data for $v \leq 45$ GeV.

Our last result, in this approximation, is shown in Fig.(3) where we consider $\Xi = (80 \pi)/180$ rad. With this choice of parameters, we can explain the new data when $v \sim \mathcal{O}(40)$ GeV. These vev values are still high when compared to the solutions, presented when we consider MRSSM and MSUS331.

3 Second Approximation

In this case, we have $\Xi_{1} = \Xi_{2} = \Xi_{3} = \Xi$ and $W$-boson mass becomes

$$M_{W}^{2} = \frac{g^{2}}{4} v_{2}^{2} \left[ 1 + \tan^{2} \beta + 3 \tan^{2} \Xi \right] . \quad (7)$$

3
Figure 1: Prediction of the mass of $W$-boson mass as a function of $v_L^3$, (see Eq.(6)), considering the parameter $\beta$ as being $(\pi/4)$ rad, for various values of $\Xi$ angles and the experimental data of the CDF is the black line.

We can get a solution with vev $v \sim 25$ GeV for $\Xi = (80\pi)/180$ rad, as showed in Fig.(4), for small $\beta$-parameter. If $\Xi = (70\pi)/180$ rad, as shown in Fig.(5), we need $v \sim 40$ GeV.

Our last plot are shown at Figs.(6,7), for $\beta = (\pi/4)$ rad and $\beta = (\pi/3)$ rad, respectively. We realize that solutions with $v \sim 10$ GeV is possible as desired.

4 Conclusions

We have considered the supersymmetric version with $U(1)_{Y'} \otimes U(1)_{B-L}$ gauge symmetry and we can explain the recent CDF measure of the $W$-boson mass if $50 \leq v_L^3 \simeq 10$ (GeV) for several values of our parameters $\beta$ and $\Xi$ as we have shown in our plots for the first assumption, see Eq.(6). We can also have solution with small vev for sneutrinos as we shown at Figs.(5,6,7).

Acknowledgement:

We would like thanks V. Pleitez for useful discussions above 3-3-1 models and about this intersting research topic. We also to thanks IFT for the nice hospitality during my several visit to perform my studies about the several Models with gauge symmetry $U(1)_{Y'} \otimes U(1)_{B-L}$ and also for done this article.
Figure 2: Similar to the previous one but with other values for Ξ angles.

References

[1] T. Aaltonen et al (CDF Collaboration), *High-precision measurement of the W boson mass with the CDF II detector*, Science 376, 170, (2022).

[2] P. Athron, M. Bach, D. H. J. Jacon, W. Kotlarski, D. Stöckinger and A. Voigt, *Precise calculation of the W boson pole mass beyond the Standard Model with FlexibleSUSY*, [arXiv:2204.05285] [hep-ph].

[3] M. C. Rodriguez, *Explain the W-boson mass anomaly in the context of the Minimal Supersymmetric SU(3)$_C \otimes$ SU(3)$_L \otimes$ U(1)$_N$ Model*, [arXiv:2205.09109 [hep-ph]].

[4] J. C. Montero and V. Pleitez, *Gauging U(1) symmetries and the number of right-handed neutrinos*, Phys. Lett. B675, 64, (2009); [arXiv:0706.0473 [hep-ph]].

[5] J. C. Montero, V. Pleitez, M. C. Rodriguez and B. L. Sánchez-Vega, *Supersymmetric U(1)$_Y \otimes$ U(1)$_{B-L}$ extension of the standard model*, Int. J. Mod. Phys. A32, 1750093, (2017); arXiv:1609.08129 [hep-ph].
Figure 3: Prediction of the mass of $W$-boson mass as a function of $v_L^3$, (see Eq.(6)), considering the parameter $\Xi = (80\pi)/180$ rad, for various values of $\beta$ angles and the experimental data of the CDF is the black line. On the (orange line) we show the Standard Model (SM) prediction, 80.3505 GeV, while on the (brown line), 80.4133 GeV, we show the world average.

Figure 4: Prediction of the mass of the $W$-boson mass as a function of $v_L^3$, see Eq.(6), for $\Xi = (80\pi)/180$ rad and several $\beta$ angles.
Figure 5: Similar to the previous one, $\Xi = (70\pi)/180$ rad, but with several $\beta$ angles.

Figure 6: Prediction of the mass of the $W$-boson mass as a function of $v_3^L$, see Eq.(7), for $\beta = (\pi/4)$ rad and several $\Xi$ angles.
Figure 7: Similar plot as presented at Fig.(6) but on this case we have $\beta = (\pi/3) \text{ rad}$. 