The $W$-boson mass anomaly and
Supersymmetric $SU(3)_C \otimes SU(3)_L \otimes U(1)_N$
Model

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Abstract

We present the Minimal Supersymmetric $SU(3)_C \otimes SU(3)_L \otimes U(1)_N$ Model as a possibility to resolves the recent deviations in the $W$ boson mass by the CDF collaboration.

PACS number(s): 12.60. Jv
Keywords: Supersymmetric models

1 Introduction

This year the CDF Collaboration reported their result of the $W$-boson mass \cite{1}

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

however the average result for $W$-mass coming from combined analyses at LEP2, Tevatron, LHC and LHCb is \cite{2}

$$(M_W)_{\text{exp}} = (80.4133 \pm 0.0080) \, \text{GeV}$$

this experimental result deviates from the Electroweak Standard Model prediction by 6.5 $\sigma$

$$(M_W)_{SM} = (80.3500 \pm 0.0056) \, \text{GeV}$$

Recently it was proposed this shift can be easily explained by an triplet Higgs boson \cite{3} and there is an attempt to explain it in the context of the Minimal Supersymmetric Standar Model \cite{4}.
From the theoretical point of view, the Electroweak Standard Model cannot be a fundamental theory since it has so many parameters and some important questions like that of the number of families do not have an answer in its context. One of these possibilities to solve this problem is that, at energies of a few TeVs, the gauge symmetry may be

$$SU(3)_C \otimes SU(3)_L \otimes U(1)_N,$$

(or it is more known as 3-3-1 for shortness) instead of that of the Electroweak Standard Model \cite{5, 6}. They are interesting possibilities for the physics at the TeV scale. In this model to give mass for the charged leptons, we need to introduce an Anti-Sextet Higgs field $S$. There are several phenomenological research on this model, some of them are given at \cite{7}.

The supersymmetric version of the 3-3-1 minimal model \cite{?} was done Refs. \cite{8, 9, 10, 11, 12} (MSUSY331). In this model beyond the anti-sextet we need to introduce a Sextet Higgs field $S'$ and its vacuum expectation value can explain the shift on the $W$ mass in similar ways as done at \cite{3}.

In the scalar sector we have an anti-Sextet $S$:

$$S = \begin{pmatrix} 
\sigma_0^1 & h^+_1 & h^+_2 \\
\frac{1}{\sqrt{2}} & \sqrt{2} & \frac{1}{\sqrt{2}} \\
\frac{1}{\sqrt{2}} & \sqrt{2} & \frac{1}{\sqrt{2}} \\
\frac{1}{\sqrt{2}} & \sigma_0^2 & -\frac{1}{\sqrt{2}} \\
\frac{1}{\sqrt{2}} & \sqrt{2} & \frac{1}{\sqrt{2}} \\
\frac{1}{\sqrt{2}} & \sqrt{2} & \frac{1}{\sqrt{2}} \\
\end{pmatrix} \sim (1, 6^*, 0),$$

(5)

and to cancel chiral anomalies generated by the superpartners of the scalars, we have to add the following higgsinos in the respective anti-multiplets:

$$\tilde{S}' = \begin{pmatrix} 
\tilde{\sigma}_0^1 & \tilde{h}_1^- & \tilde{h}_2^- \\
\frac{1}{\sqrt{2}} & \sqrt{2} & \frac{1}{\sqrt{2}} \\
\frac{1}{\sqrt{2}} & \sqrt{2} & \frac{1}{\sqrt{2}} \\
\frac{1}{\sqrt{2}} & \tilde{\sigma}_0^2 & -\frac{1}{\sqrt{2}} \\
\frac{1}{\sqrt{2}} & \sqrt{2} & \frac{1}{\sqrt{2}} \\
\frac{1}{\sqrt{2}} & \sqrt{2} & \frac{1}{\sqrt{2}} \\
\end{pmatrix} L \sim (1, 6, 0).$$

(6)

For the others particles and their quantum number see \cite{8, 9, 10, 11}. The scalar sector of this model was studied \cite{12}.

In this model as in the MSSM, we have the version where $R$-Parity is conserved, and in this case the lightest supersymmetric particle is good candidate for Dark Matter and the version where $R$-parity is broken and in this case we can give mass at tree lever for one neutrino in similar way as done in the MSSM with $R$-Parity terms as shown at \cite{13} and a preliminar analyses of the mass spectrum of this model was presented at \cite{14}.
However the sextet $S'$ can not couple with any usual fermions of our model. The superpotential of our model is given by

$$W = \frac{W_2 + \bar{W}_2}{2} + \frac{W_3 + \bar{W}_3}{3},$$

with $W_2$ having only two chiral superfields while $W_3$ has three chiral superfields. The terms allowed by our symmetry are

$$W_2 = \sum_{i=1}^{3} \mu_{i0}(\hat{L}_i\hat{n}') + \mu_{q}(\hat{n}\hat{n}') + \mu_{\rho}(\hat{\rho}\hat{\rho}') + \mu_{\chi}(\hat{\chi}\hat{\chi}') + \mu_{S}Tr[(\hat{S}\hat{S}')],$$

all the coefficients in the equation above have mass dimension \[15\] and we also have

$$W_3 = \sum_{i=1}^{3} \left[ \sum_{j=1}^{3} \left( \sum_{k=1}^{3} \lambda_{1ijk}(\epsilon\hat{L}_{i}\hat{L}_j\hat{L}_k) + \lambda_{2ij}(\epsilon\hat{L}_{i}\hat{L}_j\hat{n}') + \lambda_{3ij}(\hat{L}_{i}\hat{S}\hat{L}_j) \right) + \lambda_{4i}(\epsilon\hat{L}_{i}\hat{\chi}\hat{\rho}) \right]$$

$$+ f_1(\epsilon\hat{\rho}\hat{\chi}\hat{n}') + f_2(\hat{\chi}\hat{S}\hat{\rho}) + f_3(\hat{n}\hat{S}\hat{n}') + f_4(\epsilon_{lmn}\hat{S}_{il}\hat{S}_{jm}\hat{S}_{kn} + f_1'(\epsilon\hat{\rho}'\hat{\chi}'\hat{n}') + f_2'(\hat{\chi}'\hat{S}'\hat{\rho}')$$

$$+ f_3'(\hat{n}'\hat{S}'\hat{n}') + f_4'(\epsilon_{lmn}\hat{S}_{il}\hat{S}_{jm}\hat{S}_{kn} + \sum_{i=1}^{3} \left[ \kappa_{1i}(\hat{Q}_3\hat{n}')\hat{u}_i + \kappa_{2i}(\hat{Q}_2\hat{\rho}')\hat{d}_i + \kappa_{3}(\hat{Q}_3\hat{\chi}')\hat{J}_c \right]

+ \sum_{i=1}^{3} \sum_{j=1}^{3} \left[ \kappa_{6\alpha i}(\hat{Q}_3\hat{n}')\hat{d}_i + \kappa_{7\alpha i}(\hat{Q}_3\hat{\chi}')\hat{J}_c \right]

+ \sum_{i=1}^{3} \sum_{j=1}^{3} \left[ \kappa_{8\alpha i}(\hat{Q}_3\hat{n}')\hat{d}_i + \kappa_{9\alpha i}(\hat{Q}_3\hat{\chi}')\hat{J}_c \right]

+ \sum_{i=1}^{3} \sum_{j=1}^{3} \left[ \kappa_{10\alpha i}(\hat{Q}_3\hat{n}')\hat{d}_i + \kappa_{11\alpha i}(\hat{Q}_3\hat{\chi}')\hat{J}_c \right]

+ \sum_{i=1}^{3} \sum_{j=1}^{3} \left[ \kappa_{12\alpha i}(\hat{Q}_3\hat{n}')\hat{d}_i + \kappa_{13\alpha i}(\hat{Q}_3\hat{\chi}')\hat{J}_c \right],$$

all the coefficients in $W_3$ are dimensionless \[15\]. The terms proportional for $f_4$ and $f_4'$ were not introduced in our previous works done at \[10, 11\].

The $W$ gauge boson mass term is given by \[11, 14\]

$$L_{mass}^{\text{charged}} = M^2_W W^+ W^-,$$

where

$$M^2_W = \frac{g^2}{4}(v^2_\eta + v^2_\rho + 2v^2_{\sigma_2} + v^2_\eta + v^2_\rho + 2v^2_{\sigma_2}).$$

Therefore the $W$ mass receives an additional contribution at tree-level given by:

$$\delta M^2_W = \frac{g^2}{4}v^2_{\sigma_2}.$$
In our model the $v_{\sigma'_2}$ is free parameter and there is no bound on it because they do not give no contribution for the masses of the usual fermions.

For our numerical analyses we will apply the constraint $V^2 + V^2 + 2V^2 = (246 \text{ GeV})^2$ coming from $M_W$, where, we have defined $V^2 = v^2 + v'^2$ and $V^2 = v^2 + v'^2$ and $V^2 = v^2 + v'^2$. Assuming that $v_\eta = 20$, $v_{\sigma_2} = 10$, $v'_\eta = v'_\rho = 1$ in GeV, the value of $v_\rho$ is fixed by the $M_W$ and we will use the values of $v_{\sigma'_2}$ to explain the shift on the $W$ mass boson. Our numerical result is shown at Fig.1 where we see $v_{\sigma'_2} \leq 1$ (GeV) we get the $W$ mass given at SM and when $v_{\sigma'_2} \simeq 8$ (GeV) is required to explain the shift of the $W$ mass.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{The masses of $W$ mass in terms of $v_{\sigma'_2}$ using the parameters defined in the text, here the blue line is the mass $W$ mass at SM, see Eq.(3), while the Green line is given at Eq.(2) and the black line is CDF II value showed at Eq.(1).}
\end{figure}

2 Conclusions

In the supersymmetric 3-3-1 model we can explain the shift of the $W$ mass due the vev of our Sextet and its vev is around 8 GeV.

Acknowledgments

We would like thanks V. Pleitez for useful discussions above 3-3-1 models and about this interesting research topic. We also to thanks IFT for the nice

\footnote{As we have choose at \cite{10}.}
hospitality during my several visit to perform my studies about the several 3-3-1 Models and also for done this article.

References

[1] CDF Collaboration, T. Aaltonen et al, High-precision measurement of the W boson mass with the CDF II detector, Science376, 170, (2022).

[2] J. de Blas, M. Pierini, L. Reina and L. Silvestrini, Impact of the recent measurements of the top-quark and W-boson masses on electroweak precisions fits, [arXiv:2204.04204].

[3] J. L. Evans, T. T. Yanagida and N. Yokozaki, [arXiv:2205.03887] [hep-ph].

[4] 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].

[5] F. Pisano and V. Pleitez, An SU(3)⊗U(1) model for electroweak interactions, Phys. Rev.D46, 410, (1992); R. Foot, O. F. Hernandez, F. Pisano and V. Pleitez, Phys. Rev. D 47, 4158, (1993); R. Foot, O. F. Hernandez, F. Pisano and V. Pleitez, Lepton masses in an SU(3) L ⊗ U(1) N gauge model, Phys. Rev. D 47, 4158, (1993).

[6] P. H. Frampton, Phys. Rev. Lett.69, 2889, (1992); D. Ng, Phys. Rev. D 49, 4805(1994).

[7] E. Ramirez Barreto, Y. D. A. Coutinho and J. Sa Borges, Extra neutral gauge boson from two versions of the 3-3-1 model in future linear colliders, Eur. Phys. J. C 50, 909, (2007); E. Ramirez Barreto, Y. D. A. Coutinho and J. Sa Borges, Bounds for Z' mass in 3-3-1 models from e+ e- collisions at ILC and CLIC energies, [arXiv:hep-ph/0605098]. E. Ramirez Barreto, Y. D. A. Coutinho and J. Sa Borges, Four Leptons Production in e− e+ Collisions from 3-3-1 Model, Phys. Lett. B 632, 675, (2006); Y. D. A. Coutinho, P. P. Queiroz Filho and M. D. Tonaas, 3-3-1 exotic quark search at CERN LEPII-LHC, Phys. Rev. D 60, 115001, (1999).
[8] T. V. Duong and E. Ma, *Supersymmetric SU(3) \( \otimes \) U(1) Gauge Model: Higgs Structure at the Electroweak Energy Scale*, Phys. Lett. **B316**, 307 (1993).

[9] H. N. Long and P. B. Pal, *Nucleon instability in a supersymmetric SU(3)_C \( \otimes \) SU(3)_L \( \otimes \) U(1) model*, Mod. Phys. Lett. **A13**, 2355, (1998).

[10] J. C. Montero, V. Pleitez and M. C. Rodriguez, *A Supersymmetric 3-3-1 model*, Phys. Rev. **D65**, 035006, (2002).

[11] M. Capdequi-Peyranère and M.C. Rodriguez, *Charginos and neutralinos production at 3-3-1 supersymmetric model in e- e- scattering*, Phys. Rev. **D 65**, 035001 (2002); M. C. Rodriguez, *Double Chargino Production in e^-e^- scattering*, Int. J. Mod. Phys. **A 22**, 6080, (2008).

[12] M. C. Rodriguez, *Scalar sector in the minimal supersymmetric 3-3-1 model*, Int. J. Mod. Phys. **A21**, 4303, (2006).

[13] J. C. Montero, V. Pleitez and M. C. Rodriguez, *Lepton masses in a supersymmetric 3-3-1 model*, Phys. Rev. **D 65**, 095008, (2002).

[14] M. C. Rodriguez, *Mass Spectrum in the Minimal Supersymmetric 3-3-1 model*, J. Mod. Phys. **2**, 1193, (2011).

[15] M. C. Rodriguez, *The Minimal Supersymmetric Standard Model (MSSM) and General Singlet Extensions of the MSSM (GSEMSSM), a short review*, arXiv:1911.13043 [hep-ph].