Neutrino masses and the extra $Z^0$

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Abstract

We now know firmly that neutrinos have tiny masses, but in the minimal Standard Model there is no natural sources for such tiny masses. On the other hand, the extra heavy $Z^0$ requires the extra Higgs field, the particle generating the mass. Here I propose that the previous 2+2 Higgs scenario could be a natural framework for mass generations for both the neutrinos and the extra $Z^0$. These particles are classified as the "dark matter". Hopefully all the couplings to the "visible" matter are through the neutrinos and the extra $Z^0$, explaining naturally why the dark matter is so dark to see.

PACS Indices: 12.60.-i (Models beyond the standard model); 12.10.-g (Unified field theories and models); 14.70.Pw (Other gauge bosons).

1 Introduction

Neutrinos have masses, the tiny masses. It may be difficult to explain, since neutrinos in the minimal Standard Model are massless. In fact, this may be a signature that there is a heavy extra $Z^0$. This extra $Z^0$ then requires the new Higgs doublet[1]. This Higgs doublet also generates the tiny neutrino masses.

So, the natural clue appears in the message that neutrinos have tiny masses. The Higgs and extra $Z^0$, so weak and so heavy, would come much later in the clue (message). They all may belong to the so-called "dark matter", 25% of the present-day Universe (compared to 5% of ordinary matter).

2 Tiny neutrino masses and the new Higgs doublet

In a world of (quantized) Dirac particles interacting with the generalized standard-model interactions, there are left-handed neutrinos belong to $SU_L(2)$ doublets while the right-handed neutrinos are singlets. The term specified by

$$\varepsilon \cdot (\bar{\nu}_L, \bar{e}^-)\nu_R\varphi$$

(1)

with $\varphi = (\varphi^0, \varphi^-)$ the new Higgs doublet could generate the tiny mass for the neutrino. In the real world, neutrino masses are tiny with the lightest in the order of 0.1 eV. The electron, the lightest Dirac particle except neutrinos, is 0.511 MeV[2] or $5.11 \times 10^5$ eV. That is why the standard-model Higgs, which "explains" the masses of all other Dirac particles, is likely not responsible for the tiny masses of the neutrinos.

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1 Correspondence Author; Email: wyhwang@phys.ntu.edu.tw; arXiv:0808.2091 (hep-ph, August 18, 2008)
In a previous paper in 1987[1], we studied the extra $Z^0$ extension paying specific attention to the Higgs sector - since in the Minimal Standard model the standard Higgs doublet $\Phi$ has been used up by ($W^\pm, Z^0$). We worked out by adding one Higgs singlet (in the so-called 2+1 Higgs scenario) or adding a Higgs doublet (the 2+2 Higgs scenario). It is the latter that we could add the neutrino mass term in naturally. (See Ref.[1] for details. Note that the complex conjugate of the second Higgs doublet there is the $\varphi$ above.)

The new Higgs potential follows the standard Higgs potential, except that the parameters are chosen such that the masses of the new Higgs are much bigger. The coupling between the two Higgs doublets should not be too big to upset the nice fitting[2] of the data to the Standard Model. All these go with the smallness of the neutrino masses. Note that spontaneous symmetry breaking happens such that the three components of the standard Higgs get absorbed as the longitudinal components of $W^\pm$ and $Z^0$.

In this junction, we should say something about the cancelation of the flavor-changing scalar neutral quark currents. Suppose that we work with two generations of quarks, and it is trivial to generalize to the physical case of three. I would write

$$(\bar{u}_L, \bar{d}'_L)d'_R\Phi + c.c.;$$
$$(\bar{c}_L, \bar{s}'_L)s'_R\Phi + c.c.;$$
$$(\bar{u}_L, \bar{d}'_L)u'_R\Phi^* + c.c.;$$
$$(\bar{c}_L, \bar{s}'_L)c'_R\Phi^* + c.c.,$$  

(2)

noting that we use the rotated down quarks and we also use the complex conjugate of the standard Higgs doublet. This is a way to ensure that the GIM mechanism[3] is complete. Without anything to do the opposite, I think that it is reasonable to continue to assume the GIM mechanism.

3 A World of ”Quantized” Dirac Particles

Coming to think about it, we can rephrasing the Standard Model as a world of quantized Dirac particles with interactions. Dirac, in his relativistic construction of Dirac equations, was enormously successful in describing the electron. Quarks, carrying other intrinsic degrees (color), are described by Dirac equations and interact with the electron via gauge fields. We also know muons and tau-ons, the other charged leptons. So, how about neutrinos? Our first guess is also that neutrinos are Dirac particles of some sort (against Majorana or other Weyl fields). For some reasons, Dirac particles are implemented with some properties - that they know the other Dirac particles in our space-time. (We are trying to avoid some bias in saying that it is a Dirac particle. Some magic occurs here.)

So far, this has been true that it is a world of Dirac particles with interactions. If we simplify the world to that, maybe a lot of questions could be answered. How little we have progressed in terms of the relativistic particles, if the view regarding the world of quantized Dirac particles prevails!

What is also surprising is the role of ”renormalizability”. We could construct quite a few such extensions of the minimal Standard Model - the present extra $Z^0$ and the recent proposed family gauge theory[4]; there are more. Apparently, we should not give up though the road seems to have been blocked.
4 A Simple Connection to the Unknowns

It turns out that a world of Dirac particles as described by quantum field theory (the mathematical language) is the physical world. The interactions are mediated by gauge fields modulated slightly by Higgs fields. There may be some new gauge fields, such as the extra $Z'$ or the family gauge symmetry or others, but the first clue is the neutrino masses - and the next clue will be weaker and subtler, and even weaker.

There are a bunch of dark matter out there - 25% of the present Universe compared to only 5% ordinary matter. When we get more knowledge on the dark matter, we may have pretty good handles of this Universe.

Acknowledgments

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(September 9, 2010; Revised May 23, 2011)

Abstract

We now know firmly that neutrinos have tiny masses, but in the minimal Standard Model there is no natural sources for such tiny masses. On the other hand, the extra heavy $Z^0$ requires the extra Higgs field, the particle generating the $Z^0$ mass and also the neutrino tiny masses. Here I propose that the previous 2+2 Higgs scenario could be a natural framework for mass generations for both the neutrinos and the extra $Z^0$. These particles are classified as the "dark matter". Hopefully all the couplings to the "visible" matter are through the neutrinos and the extra $Z^0$ via the so-called "minimum Higgs hypothesis", explaining naturally why the dark matter is so dark to see.

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1 Introduction

Neutrinos have masses, the tiny masses. It may be difficult to explain, since neutrinos in the minimal Standard Model are massless. In fact, this may be a signature that there is a heavy extra $Z^0$. This extra $Z^0$ then requires the new Higgs doublet[1]. This Higgs doublet also generates the tiny neutrino masses.

To think of it more, we may invoke the so-called "minimum Higgs hypothesis" (to account for the fact that we are yet to see the Higgs particle after searching for it over the last forty years). So, the extra $Z^0$ and the required new Higgs doublet would be everything which we should consider, if there is nothing else. This brings us back to the 2 + 2 extra $Z^0$ model[1]. To be honest, it might be too much to assume that "there is nothing else" - how about the missing the right-handed sector or the family "gauge" symmetry (to explain way the occurrence of the three generations)? In this brief report, our minds are so over-simplified that the extra $Z^0$ plus one new Higgs doublet is the story.

There might be some difficulties as regarding that, in the present Universe, there is 25% dark while only 5% visible ordinary matter - the picture of the extra $Z^0$ plus the new Higgs doublet may sound too simple and too little to account for the dark matter world. But we should analyze its consequences since the situation calls for.

So, the natural clue appears in the message that neutrinos have tiny masses. The Higgs and extra $Z^0$, so weak and so heavy, would come much later in the clue (message). They all may belong to the so-called "dark matter", 25% of the present-day Universe (compared to 5% of ordinary matter).

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2 Tiny neutrino masses and the new Higgs doublet

In a world of point-like Dirac particles interacting with the generalized standard-model interactions, there are left-handed neutrinos belong to $SU_L(2)$ doublets while the right-handed neutrinos are singlets. The term specified by

$$\lambda' \cdot (\bar{\nu}_L, \bar{e}^-) \nu_R \varphi$$

with $\varphi = (\varphi^0, \varphi^-)$ the new Higgs doublet could generate the tiny mass for the neutrino. Let call it the “remote” Higgs doublet.

In the real world, neutrino masses are tiny with the heaviest in the order of $0.1$ eV. The electron, the lightest Dirac particle except neutrinos, is $0.511 \text{ MeV}$ or $5.11 \times 10^5$ eV. That is why the standard-model Higgs, which ”explains” the masses of all other Dirac particles, is likely not responsible for the tiny masses of the neutrinos.

In a previous paper in 1987[1], we studied the extra $Z^0$ extension paying specific attention to the Higgs sector - since in the minimal Standard Model the standard Higgs doublet $\Phi$ has been used up by $(W^\pm, Z^0)$. We worked out by adding one Higgs singlet (in the so-called 2+1 Higgs scenario) or adding a Higgs doublet (the 2+2 Higgs scenario). It is the latter that we could add the neutrino mass term in naturally, according to ”the minimum Higgs hypothesis”. (See Ref.[1] for details. Note that the complex conjugate of the second Higgs doublet there is the $\varphi$ above.)

The new Higgs potential follows the standard Higgs potential, except that the parameters are chosen such that the masses of the new Higgs are much bigger. The coupling between the two Higgs doublets should not be too big to upset the nice fitting[2] of the data to the Standard Model. All these go with the smallness of the neutrino masses. Note that spontaneous symmetry breaking happens such that the three components of the standard Higgs get absorbed as the longitudinal components of $W^\pm$ and $Z^0$.

To be specific, let the vacuum expectation values be $v$ and $v'$, as determined by the Higgs potentials. The couplings of the standard Higgs to quarks and charged leptons are of order $O(\lambda)$. The couplings of neutrinos to the ”remote” Higgs are of order $O(\lambda')$, which would be $(v/v')^2 \cdot O(\lambda)$ in view of the ”minimum Higgs hypothesis”.

In other words, the details about the mass generation, through the couplings of Higgs to the various particles, should be the next important question in the Standard Model. The ”minimum Higgs hypothesis” offers us an avenue to simplify our thinking in this direction. First, we think that the reason for the tiny masses of neutrinos is an important clue - it does not come from the standard Higgs since otherwise the range of what would be given by the standard Higgs is of order $10^{15}$, too wide the range. Second, for the quark sector, the standard Higgs should be adequate according to the minimum requirement - see the next paragraph for more. Thirdly, neutrinos should not couple to the standard Higgs, but yes to the remote Higgs. Strangely enough, all these come from the ”minimum Higgs hypothesis”.

We could also say something about the cancelation of the flavor-changing scalar neutral quark currents. Suppose that we work with two generations of quarks, and it is trivial to generalize to the physical case of three. We would write

$$(\bar{u}_L, \bar{d}_L')d^c_R \Phi + \text{c.c.};$$
$$\bar{c}_L, \bar{s}_L')s^c_R \Phi + \text{c.c.};$$
\[
(\bar{u}_L, \bar{d}_L) u_R \Phi^* + c.c.;
(\bar{e}_L, \bar{s}_L') e_R \Phi^* + c.c.,
\]
noting that we use the rotated down quarks and we also use the complex conjugate of the standard Higgs doublet. This is a way to ensure that the GIM mechanism[3] is complete. Without anything to do the opposite, I think that it is reasonable to continue to assume the GIM mechanism.

The question is that why we have only one Higgs doublet doing the job (the GIM mechanism). The ”minimum Higgs hypothesis” may be the answer.

3 A World of ”Point-like” Dirac Particles

Coming to think about it, we can rephrasing the Standard Model as a world of point-like Dirac particles with interactions. Dirac, in his relativistic construction of Dirac equations, was enormously successful in describing the electron. Quarks, carrying other intrinsic degrees (color), are described by Dirac equations and interact with the electron via gauge fields. We also know muons and tau-ons, the other charged leptons. So, how about neutrinos? Our first guess is also that neutrinos are point-like Dirac particles of some sort (against Majorana or other Weyl fields). For some reasons, point-like Dirac particles are implemented with some properties - that they know the other point-like Dirac particles in our space-time.

So far, this has been true that it is a world of point-like Dirac particles, or quantized Dirac fields, with interactions, mediated by gauge fields and modulated slightly by Higgs fields. This phenomenon, which we call ”Dirac similarity principle” in my other paper, reflects a lot about our four-dimensional space-time. In our physical four-dimensional space-time, our efforts to define ”point-like” may stop here. Particle physics serves to describe the ”point-like” Dirac particles in this space-time.

What is also surprising is the role of ”renormalizability”. We could construct quite a few such extensions of the minimal Standard Model - the present extra \(Z^{0}_t\), the left-right model[4], and the family gauge theory[5]; there are more. Apparently, we should not give up though the road seems to have been blocked.

4 A Simple Connection to the Unknowns

It turns out that a world of point-like Dirac particles as described by quantum field theory (the mathematical language) is the ”smallest” physical world. The interactions are mediated by gauge fields modulated slightly by Higgs fields. There may be some new gauge fields, such as the extra \(Z^{0}_t\) extension[1], the left-right model[4], or the family gauge symmetry[5], or others, but the first clue is the neutrino masses - and the next clue will be weaker and subtler, and even weaker. Here, besides the extra \(Z^{0}_t\), we name the left-right model and the family gauge symmetry for the reason that the left-right symmetry is some symmetry missing (but for no reasons) while the duplication of the generations should be for some reasons.

There are a bunch of dark matter out there - 25% of the present Universe compared to only 5% ordinary matter. We have the Standard Model for the 5% ordinary matter and
we should expect to have the theory to cover the 25% dark matter. When we get more knowledge on the dark matter, we may have pretty good handles of this Universe.

Acknowledgments

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References

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