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Revisiting Constraints of Fourth-Generation Quarks and Leptons

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Standard Model is well-performing under the three-generation, but in the wake of more physics, fourth-generation leptons and quarks are introduced. In this paper, We will be reviewing various constraints surrounding quarks and leptons of 4th Generation and tried to show the importance of quarks to understand the baryogenesis. We talked about, reviewed existing parameters and set the updated lower limits of t' and b' by analysis. And predicted an updated version of lower mass bounds quarks and leptons. It is also reviewed that fourth-generation leptons are primarily not possible because of disintegration of Higgs Boson and an interpretation has been setup. And in final, we talked about the Unified Standard Model.

Keyword Beyond the Standard Model; Fourth Generation Particles; Lepton Sector; Quarks Sector

1. INTRODUCTION

In recent years the SM4, the upgraded version of SM3 has been in point of attraction by many physicists. After the last piece, Higgs Boson in the SM3, there are many questions in paucity about the masses of next Leptons and Quarks. In SM3, the mass of Higgs Boson is 125.18 ± 0.16 GeV [1]. In SM4, few authors have updated the mass of Higgs Boson around 115 GeV (but we need to stick with our LHC found mass). With the extension of SM3 to SM4, we just add a couple of Leptons and Quarks, Quarks t' and b' with isopin of $\frac{1}{2}$ and $-\frac{1}{2}$ respectively (but that is not the case, we will see it later) and Lepton l' and its corresponding Neutrino. There are a lot of discussions about the masses and flavor mixing of leptons and quarks. In our model, we will be looking at the current Koide Formula (Hypothesis) [2]: [1]

$$Q = \frac{m_e + m_\mu + m_\tau}{(\sqrt{m_e} + \sqrt{m_\mu} + \sqrt{m_\tau})^2} \approx 0.666661 \approx \frac{2}{3} \quad (1)$$

for theoretical masses of leptons and quarks, albeit the validity of Koide Hypothesis is not yet determined, but this is the incredible yet not definable formula. If Koide formula holds true then calculated mass of b' ≈ 3.6 TeV and mass of t' ≈ 84 TeV, perhaps it is common to take lower bound of b' to be > 1.3 - 1.6 TeV (precisely lower bound of b' excluded at 338-362 GeV, see more in reference [3]). The leptonic mass for l' and Neutrino $V_{l'}$ is quite an in danger because of LHC constraints, LEP experiment using the width of Z Boson has measured that total number of Neutrino must be 3 [4], with high precision.

But there is a way to cancel the anomaly, we can assume that the mixing of this neutrino is so less with another neutrino, so we have to assume that its mass must be big enough. Also charged lepton, $m_{l'} < 100$ GeV is also excluded by another LEP experiment. Hence we must put the lower bound of lepton and neutrino $m_{v_{l'}} \leq \frac{1}{2} M_Z$. We can assume the identical lower bound for charged lepton $m_{l'} \sim \frac{1}{2} M_Z$. But there is another anomaly, if the mass is correct, then Higgs Boson would decay to a pair of neutrinos.

The reason for taking these masses of quarks a thousand times the third generation quarks is because we want to know the Baryon Symmetry CP Violation, which is a strong candidate for Sakharov conditions [5]. The CP Violation is suppressed by s, c, and b quarks because of their low masses [6]. If these new quarks are proven(which is not possible now) then we can admit that baryon asymmetry is the reason because of these heavy quarks. It is widely accepted that CP Violation is necessary to get the Baryogenesis.

Although it has been challenged that $N_v = 3$, many physicists including me still rely on that neutrinos are not yet studied well in the frame of SM3. Also, the concept of 10^{13} or more gain in CPV strictly made us favor SM4 over SM3. If we ignore few parameters and anomalies(that we can't) then, SM4 is perfectly good for understanding the early universe as well as digging more literature in Physics.

With so much constraints [7], there are still a lot of expectation when one goes to SO(N) and SU(N) where N is normally larger (we are talking about GUTs) which is basically emphasized in [8].

2. HIGGS BOSON IN SM4

The anomaly we discussed above contains a whole set of new literature. That eventually rule out whole leptons discussion. In SM4, our $M_H \approx 125$ GeV (yes, because we are needed to stick to the LHC masses) and the decay branch $H \rightarrow v'\bar{v}'$. Along with $H \rightarrow b\bar{b}$, $H \rightarrow gg$, $H \rightarrow \gamma\gamma$, $H \rightarrow v'\bar{v}'$, $H \rightarrow WW$ and $H \rightarrow ZZ$, Higgs Boson gets more complicated as scalar (you can check the branching ratios in [4]). In those figures the masses are updated with SM4 parameters, where heavy leptons masses are set to $m_{l'} = m_{v'} + 50$ GeV [4]. Although the fate of the

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[1] Koide Formula is outdated now.

$H \rightarrow v'\bar{v'}$ is criticized a lot with the data of ATLAS and CMS, this branching can introduce a lot of new chain reaction as this heavy neutrino get further decay(but in this case of fourth-generation $v'_{l'}$ it might not). Talking about this neutrino is so dangerous, as if the mass of the neutrino is too large then it will suppress by the factor < 10 to decay. If the new heavy neutrino doesn't decay then weak interactions of other decays of neutrinos(v_e, v_μ, v_τ) becomes a mystery, it is quite not a possible thought that some neutrino does decay others don't. Hence it is quite tough to explain the fourth generation leptons, so we simply exclude these leptons because ATLAS and CMS reported (see ref [9], [10]) $H \rightarrow \gamma\gamma$ signal with a significance of more than 4 standard deviations from the SM4. The factor observed was 1.9 ± 0.5 for ATLAS and 1.56 ± 0.43 for CMS which is much low in SM4, maybe because of channel $H \rightarrow v'\bar{v'}$ which is not appropriate for Standard Model. Also in SM4, one must expect more enhanced data of $H \rightarrow \tau\tau$ channel which is not observed in current data. So our assumption of $m_{v'} \approx \frac{1}{2} M_z$ is kind of false, see reference for more [4], [11].

This alone seals the fate of fourth-generation leptons, along with the accurate prediction of $N_v = 3$ [12] by Z width(LEP). But I still doubt the insufficient experimental data and quite of favor SM4 in the wake of more study of v'_l neutrino, the matter of the existence of this neutrino depends on the mass of this neutrino. But for now, fourth-generation leptons are not quite likely to be found in accelerators.

There is also another possibility of being it from another model, not from SM4, actually, this neutrino would have negligible coupling to any observed particle of SM3. Or it has it's own coupling family, I mean to say another particle physics model, which we are not ready for.

3. QUARKS IN SM4

While you see the lepton fourth-generation section is destroyed with observational data, there are still possibilities of finding heavy quarks of masses that we have assumed. Quarks are the way and in my way, it is the only way to understand the dominance of matter over anti-matter, i.e Baryogenesis [13]. If this holds true then, our 6 flavors quarks with gluons of SU(3) symmetry is not yet completed. Well, the question arises, what is the significance of heavy quarks and why we need them?

The heaviest quark we have is a top quark with a mass of 173.2 ± 1.0 GeV with its ad-joint quark with a second-heaviest bottom quark with a mass of 4.20 ± 0.04 GeV. These two quarks are not much found, but does make us understand the strong force and other phenomena.

Using the view of an experimentalist, it is quite easy to tell that our standard model is complete. But theoretically, it is not yet ready, as the current standard model not precisely tell us the answer related to questions like:

1. Exclusion of gravity.
2. Why there is not any specified coupling constant for gravity in field theory?
3. Dominance of matter over anti-matter
4. Maybe why and how dark matter behave?

The gravity thing and the coupling constant concept are the goals of now-days physicists. It is called the unification of gravity with other forces. But no theories such as supersymmetry, string theory (although it is the best candidate for unification) can prove GUT, perhaps not now. So our clear indication goes to Standard Model (albeit all those candidate prerequisites is particle physics, but many physicists goal to have unification on the sole base of particle physics) for unification, more concretely using the particles and quarks system that we have and that we haven't.

I will more emphasize here on the 3rd list. That is the dominance of matter over anti-matter. In SM3 the heaviest mass is 173.2 GeV, and Sakharov's condition [5] of CP Violation doesn't favor this mass. I can cite many papers and articles [6], [14] where the heaviest quarks are needed to properly guess the baryon to anti-baryon ratio. If we prefer b' and t', then CP Violation must have some key role in the early universe.

It can be seen that for every baryon there are 2×10^9 photons at 2.7 K in CMBR (Cosmic Microwave Background Radiation) [15],

$$\frac{n_B}{n_\gamma} = 5 \pm 0.3 \times 10^{-10} \tag{2}$$

however, we don't see that much anti-baryon in this scenario. However, we have some sufficient things in our current SM model, which can define this anomaly. But to a certain level, and we see that s, b and c are suppressed by a factor of 10^{-13} (if we are not wrong) because of their masses 95^{+9}_{-3} MeV, $4.18^{+0.04}_{-0.03}$ GeV and $1.275^{+0.025}_{-0.035}$ GeV respectively. Believe me, it is all about the masses that come into the play, if we just compare strange mass to lower bound of b' with s quark, then the ratio comes,

$$\frac{m^{lb}_{b'}}{m_s} \geq 15.3 \tag{3}$$

and if we take our hypothetical mass then it goes to almost 35 factors. Where m^{lb} is the lower bound mass of b'. Similarly in the case of t', it is perhaps even bigger or biggest ratio, i.e the factors of 854. The ratio of t' and t quark is somewhere 482 with ±10. You can judge how the big mass would be. This is just speculative and pretty awesome. [3].

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We can't possibly (we mean fact fully) talk about decays of t' unless and until we have precise upper bound and lower bound of t'. But we can say that decay would have t quark and boson (simply W or Z). But one possibility is determined, if $m_t' > m_b$', then $t' \rightarrow b'W$. And there is a particularly neat decay of b' when the mass splitting is bigger than m_W, then $b' \rightarrow t'W^-$ and the quite twin result we have seen above. Another possibility is when $m_{b'} + m_W > m_{t'} > m_{b'}$, then the decay would have $t' \rightarrow qW^+$, where q = c, t, u [16]. Other possibilities are:

- $t' \rightarrow b'W^*$ where W^* is a virtual W-Boson.
- $t' \rightarrow qW^+$ where q = d, s, b.

But in our model, the first ones are considered to be of high precision and mostly found. Perhaps, if we question the heavy mass of t quark, W and Z boson, then we can say that they are the product of the heaviest quark t' (in this scenario).

Back to the Sakharov Conditions, CP invariance, according to the idea, the universe, more precisely the hot expanding universe* was not invariant under CP symmetry. Although we have not any experimental evidence for this (besides some legit observations), various decays are reported claiming this.
In case of our CPV which fell sort of 10^{-10} after the best effort in SM3. By including two more CPV phases as compared to SM3, Baryogenesis is possible with the dynamics that already exist in the Standard Model (current one). So we say that including the fourth generation is interesting and a small revolution as a whole. Learning about the electroweak symmetry and baryon asymmetry is the key to the standard model. Fourth-generation quarks are even interesting, as one gets a CPV factor gain of 10^{10} or even more. Indeed there is a very interesting figure representing the knowledge of ours as compared to the fourth generation CPV knowledge.

Despite the efforts that we are doing to combine the physics to a unnatural model (for now) we are left with to check it inconsistency with Electroweak precicions, which is available in [17], [8], [18],.

4. THE SM4 MODEL INCOSISTENCY

After discussing our constraints and putting the number of ideas with the available and non-available option, it can be seen that the physics of particles are not complete. Our current model scales from $0.1 MeV$ to 173 GeV and the mass difference is about 83827 GeV from t to the next generation t'. It can be noted that my primary focus is mass. Because the difference is amazing and if the LHC in the future can predict these quarks, it is then going to be a completely new generation for new generation physicists. But one common question arises.

Is Fourth Generation Quarks possible without Fourth Generation Leptons?

As we have revisited the whole problem with my perspective, and I still believe in fourth-generation leptons (theoretically). But I have myself declared that more mathematics is needed to build the foundation for heavy leptons such mass as $\frac{1}{2}M_z$ and $\frac{1}{2}M_H$. The parameters are not that free. So we excluded it. But there is a history revolving around, there are equal generations of quarks and leptons. Can we violate it?

There are mixed answers related to this, firstly, we think of course, we certainly don't see that as a mathematical boundary, so no one is obliged to not cross that statement. However, if we take an additional gauge group SU(5) in the model, things get better. Like we get the mass that we want and we get the possibility of freedom in fourth-generation quarks [19] (But things get more complicated as SU(5) breaks the symmetry, more in Appendix 1).

In short, it is possible. But only theoretically now, but soon it may turn out to be wrong or just a fantastic right. And the Unified Standard Model, then would have at least 14-16 particles. And we may get closer to asymptotically freely QCD. It may be a dream of a theorist to be considered correct in this case (we are from this group) and a determination of experimentalist at the accelerator. But on the other hand, we will lost the conservation of axial current in unification of Elctroweak as there is requirement of $\Sigma Q_i = 0$ in each family [20]. Though we are not free, but we can afford it to construct a toy model.

4.1. The Failures Beyond Third Generation

While, this paper can be seen as a support of Fourth Generation Quarks and maybe Leptons, but there is a lot of problems that this kind of theory faces. In this sub-section, we will be reviewing the problems under the fourth generation.

To get to the point, we may add a chiral doublet quark (or lepton), where SU(2) performs the action for left-handed components and right-handed components may transform as singlets. But chiral doublets and singlets of quarks and leptons come with anomalies [8]. In other SM, it is easy to discard the anomaly by introducing a mirror doublet. But that's not the case in SM4. The problem to solve CP problems without predicting axion can have consequences of a non-chiral doublet of quarks or non-chiral singlets. And the most important consequence when we try to add fermions and quarks is of course the masses of different particles of SM3. So, it is much unlikely that we find additional quarks and leptons, in the near time.

Conclusion

We started with masses of various fourth-generation quarks and leptons, by mixing it with our idea of mass. And found the lower bound to be 1.3 TeV for b' and 4 TeV for t' (in our model, however, we discussed other models as well). Then we examined the mass of neutrino and leptons of fourth-generation and constrained it at the mass of half the Z-Boson. After that, we performed the Higgs Boson scenario in SM4 and showed the anomaly. Then we dropped the idea of fourth-generation quarks. We talked about the existing constrained value and tried to explore it. Later we talked about the new physics that can be unlocked by including fourth-generation quarks and proved how successful it will be. Then we measured the various parameters ratio and found it much bigger than any ratio we have seen in the context of particles. And In the end, we talked about the possibility of quarks without leptons and predicted t' and b' to be interesting and if found then it will be another victory of physics.

At last, we can say that there is still a possibility of finding these additional quarks and leptons (although faded). But if these are found, then there will be revolution in search of more leptons and quarks (the unknown particles of nature)

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Appendix 1

Flavor Symmetry is one of the biggest problems in QCD. While SU(2) seems to be good, SU(3), SU(4) and so on terribly break the symmetry in particle physics. Especially in Quarks Section, SU(4) and so on gives us a terrible break in symmetry. The conditions and the masses we are reviewing here, also don't follow any symmetry, as SU(8) is very far complicated to be fitted in Symmetry even though we haven't even succeeded in the SU(4). The masses difference between quarks after down quarks are very large, and in SM4 it gets more difference. We have at least 80 orders of difference between t' and b'. So there is not any chance of flavor symmetry in SM4 either. So the isospin of these quarks is also 0, $I = 0$. As we said in first section that isospin exits, but we come to conclusion that it doesn't.

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