A possible origin of the q=4/3 diquark

A. Rivero ∗†

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Abstract

Between the new physics candidates proposed to explain the $t\bar{t}$ asymmetry measured in the Tevatron, there are some scalar diquarks with electric charge $+4/3$. This kind of diquark is also needed to classify all the scalars of the supersymmetric standard model, with three generations, under a global flavour symmetry.

1 Introduction

One of the measurements that have caused some stir during the last run of the Tevatron has been the forward-backward asymmetry[1] of top quark processes. Between the different New Physics candidates that have been proposed (see [2] for a short review), some scalar “diquarks” in diverse multiplets are favoured, and particularly [4] some isosinglets with charge $4/3$.

While the hint is generically towards flavour models, here we want to show that when flavour is imposed not in the standard model fermions but in the scalar sector (squarks and sleptons) of the supersymmetric SM, the candidate particles appear inside a very unique construction, that exhausts exactly for three generations with five light quarks. We explain this fact in the first section of the paper and then we proceed to speculate on other uses of a flavour symmetry inspired in composites.

2 Flavour in susy scalars

Independently of its physical interpretation, it is possible to use a flavour $SU(5)$ to classify the 24 sleptons contained in the SSM -when extended with right neutrinos-. This is done by taking this representation from $5 \otimes \bar{5} = 24 \oplus 1$ and then branching it down to $SU(3) \times SU(2)$.

$$24 = (1,1) + (3,1) + (2,3) + (2,\bar{3}) + (1,8)$$

Giving an electric charge $+2/3$ to the $SU(3)$ piece and $-1/3$ to $SU(2)$, it can be seen that we have got a sextet of charge +1, another opposite sextet of charge −1, and another twelve states of zero charge. The construction can be

∗Institute for Biocomputation and Physics of Complex Systems, University of Zaragoza
†al.rivero@gmail.com, arivero@unizar.es
done for any odd number of generations, but it becomes specially elegant -and unique in some terms- when done for three.

Now, we produce all the squarks from the same flavour group by taking the 15 of $5 \otimes 5 = 15 \oplus 10$. With the same branching, it decomposes as

$$15 = (3,1) + (2,3) + (1,6)$$

so that we get one sextet of charge -1/3 and another sextet of charge +2/3. We call this reproduction of the original charges a “supersymmetric Bootstrap”, or sBootstrap for short, because it is possible to interpret the SU(3) piece as coming from three particles similar to quarks $d, s, b$ and the SU(2) piece similar to quarks $u, c$. If we pursue this interpretation, the uniqueness is more appealing: with more of three generations, not all of them are used in the flavour symmetry, and the number of extra particles makes the scheme a lot uglier, adding more exotic squarks and sleptons to the bag. Note that also the same interpretation, with the same “quarks”, applies to the 24 decomposition on sleptons above.

This symmetry was found some years ago in [12] and the uniqueness is discussed with more detail there, but even with three generations it had a severe handicap: the 15 multiplet has three extra scalars not in the standard model. Fortunately, they were different from the other scalars in the sense that, being an odd number, it was not possible to arrange them in Dirac supermultiplets; then this chirality was expected to be an advantage allowing either to eliminate them from the game board or to force them into the gauge sector (more on this later). But an acceptable, fully developed solution has not been found yet.

What is important for this brief letter is to notice what this (3, 1) triplet is: the three scalars have charge +4/3 and can be assigned interactions as a scalar diquark. It is then the same kind of particle expected to solve the Tevatron asymmetry.

We can read this in two ways: on one direction, it could be said that an extra flavour symmetry for the scalar sector of SUSY predicts the need of 4/3 diquarks. On the reverse direction, it is possible that most of the models proposed to explain the asymmetry will exhibit explicitly a scalar flavour symmetry when super-symmetrized. On the side of model builders, it may mean some extra work, because besides a colour triplet we also have a flavour triplet (naively, $uu, uc + cu$ and $cc$ like states). The degeneracy could be removed in some flavour-colour locking scheme, or it could be really there.

The initial idea in [12] was to interpret all those scalars as the well known spectrum of mesons, plus a diquark spectrum hidden inside baryons. That implied some complications: besides being composites, the supersymmetry needed to work between particles with different baryon and lepton number. Probably this is still the case here, but with a revenge: if the +4/3 particles are real states on their own, and no just QCD diquarks, the argument to keep insisting in the original idea becomes even weaker; the next resort is to consider all the scalar states as formed by condensation via some technicolor force, beyond QCD but very similar to it.

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1. I thank M. Porter by this observation.
3 A mass spectrum.

Having stated the main point, let’s allow for an *Intermezzo*: If SUSY has a flavour symmetry of its own, based on composites, is a mass formula possible?

It could be, and it could be that remnants of the mass formulae are still visible in the fermion sector even after SUSY breaking. This idea was part of the motivation for this research, back in 2005, when some attention was dedicated to Koide equation [6, 7, 8] and its repercussions in neutrino spectrum (e.g. [3]). This equation is an evolution of the formulae for masses and Cabibbo angle that were justified in the late seventies using textures [10], democratic matrices, or permutation symmetry in $SU(2)_R \otimes SU(2)_L$ models [11].

Recent empirical work [14, 13] has extended Koide formula from leptons to quarks then bringing the equation back to its birthplace. The $m_e = m_u = 0$ spectrum, see [13] could be an interesting starting point for the search of a supersymmetrical spectrum. Remember that the LR models for Cabibbo angle used to permute the $R$ sector in a way that the bottom $R$ quark was related to the up $L$ quark; if we cannot put the superpartners of a $m_u = 0$ quark at zero -say, if we do not want the lowest energy state to be degenerated- then we can still put them at the energy of the $b$ quark.

4 Towards technicolor

Finally, we wonder if, besides to explain the $t\bar{t}$ asymmetry, is it possible to exploit these diquarks in some Higgs-like scenario. The peculiar charge of these particles seems an impediment, but there is an interesting possibility: that some of this charge comes from $B-L$ in a non-chiral way. This is a typical feature of GUT models using a left-right symmetry.

From this perspective, the $(3, 1)$ diquarks should be seen as having some non-chiral interactions, providing colour and a piece of $Q_v = \frac{1}{3}(B-L) = \frac{1}{3} \times \frac{1}{3} = \frac{1}{3}$ of electric charge, plus a chiral interaction providing the existing $Q_{ch} = +1$. If the condensation mechanism can get rid of the vector part of the interaction, our diquarks seem more alike the scalars of the gauge supermultiplets: color neutral and with integer electric charge. Looking B-L in a different foot that the rest of the symmetries is interesting because it also imply that we increase our disbelief in R-symmetry. You could have noticed that the scalars we are producing have a B-L value different in one unit respect to the fermions they are supposed to partner with.

Furthermore, color neutrality causes a degeneration, and the number of different states is now only three particles and the corresponding antiparticles. Under SUSY, the massless gauge supermultiplet needs to eat one chiral supermultiplet (with a fermion and two scalars) to get mass; one of the scalars becomes the extra degree of freedom of the W or Z, and the other surfaces as a Higgs scalar. Thus it is interesting that under color neutrality, and barring the degeneration -or controlling it with some flavour-colour locking, appropriate also to the discussion in the first section-, we get the number of scalars needed to make three chiral supermultiplets. Some work is being done to try to introduce these ingredients in an EWSB mechanism, but it is still in very early stages.
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