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A SEARCH FOR EXOTIC PARTICLES OF CHARGE 5/3 WITH THE CMS DETECTOR

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Dipartimento di Fisica e Astronomia
Università degli Studi di Padova

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Ohana means family.
Family means nobody gets left behind, or forgotten.

— Lilo & Stitch

Dedicated to the loving memory of Rudolf Miede.

1939 – 2005

ABSTRACT

Short summary of the contents in English…

ZUSAMMENFASSUNG

Kurze Zusammenfassung des Inhaltes in deutscher Sprache…

We have seen that computer programming is an art,
because it applies accumulated knowledge to the world,
because it requires skill and ingenuity, and especially
because it produces objects of beauty.

— **?** [**?**]

ACKNOWLEDGMENTS

Put your acknowledgments here.

Many thanks to everybody who already sent me a postcard!

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1 Members of GuIT (Gruppo Italiano Utilizzatori di TeX e LaTeX)

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1.1 THE STANDARD MODEL

The SM is a quantum field theory developed in the 1970s. It describes matter and the electromagnetic, weak and strong nuclear forces in terms of point-like particles.

The most profound insight in the SM is that all of these interactions are determined by symmetry principles, called local gauge symmetries. This idea is connected with the fact that the conserved physical quantities, e. g.electric charge, are conserved at every point in space-time, and not just globally. This connection is given by Nöther's theorem in the lagrangian formalism.

The treatment of one particular property of the particles requires some ingenuity. Mass terms are not allowed in the SM lagrangian, because they break the fundamental symmetry principles. Yet it is obvious from observation that most particles have mass. The Higgs mechanism with spontaneous symmetry breaking was devised to solve this problem, and appears to be close to experimental confirmation at the time of writing.

We will first review the features of the unbroken SM, then introduce the Higgs field and finally present some shortcomings of this theoretical description.

A complete description can be found elsewhere, the following section will highlight the material that is relevant to the problems we are investigating in the rest of our work.

1.1.1 *The unbroken SM*

All of the matter particles in the SM are fermions, and are usually divided in two categories: particles that feel the strong force, called *quarks*, and particles that do not, called *leptons*. Quarks and leptons are grouped into three *families* or *generations*. Particles from different generations have exactly the same properties, except for mass. The origin of this family structure is still unknown.

A force is introduced by requiring the lagrangian for the matter fields to be invariant under a group of space-time dependent transformations, called *gauge* transformations.

The theory of QED was the first succesful gauge theory. It describes the electromagnetic force, with a $U(1)$ gauge invariance. As a consequence, a *gauge boson* has to be introduced to preserve the local symmetry, that is the photon.

The electromagnetic and weak forces are then unified by a gauge group $SU(2)_L \times U(1)_Y$, with the L subscript denoting the fact that the $SU(2)$ gauge transformations only involve the left-handed fermions. The Y subscript is intended to indicate that this $U(1)_Y$ group is not the same as the aforementioned group for QED. The number of gauge bosons must be the same as the dimension of the gauge group, so that we now get four vector bosons: the photon, the $W^{\pm}$ and the Z.

The description of the strong force involves the group $SU(3)$. The charge of the strong force is called *colour*, it is carried by eight bosons called *gluons*. Figure 1 summarizes the particle contents of the unbroken SM.

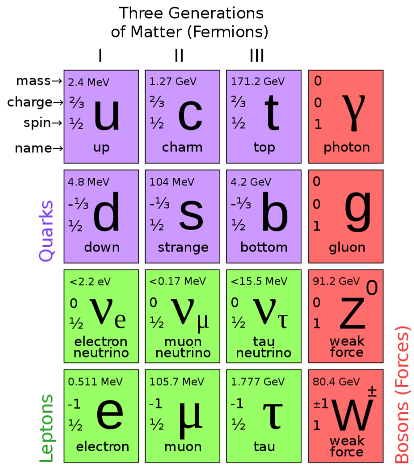

Figure 1: The particles in the unbroken SM.

1.1.2 *Spontaneous simmetry breaking: the Higgs mechanism*

We have only considered massless particles. This is not the case for all the known fermions, and for the Wand Zbosons. A mechanism was proposed to preserve the gauge invariance of the lagrangian, while the vacuum state is no longer a singlet under the action of the gauge group.

Spontaneous symmetry breaking of the local gauge symmetry in the SM provides massive Wand Zbosons and a new boson, called the Higgs boson. In addition, we can obtain massive fermions by coupling them to the Higgs field with Yukawa terms.

1.1.3 *The hierarchy problem*

Recently found evidence for a light Higgs boson, with a mass near 125 GeV, are thought to be an indication of new symmetries and new particles beyond the SM.

The theory predicts that the mass m_H is subject to large radiative corrections from loop diagrams, that should increase it by a large amount. In the SM, fine tuning is required to prevent this corrections from becoming too large. Theoretical physicists generally dislike this fine tuning on grounds of *naturalness*.

The most notorious example of an extension to the SM that can eliminate this naturalness problem is supersimmetry, where the radiative corrections to the Higgs mass of the SM fermions are canceled by their superpartners.

There exist many theories that do not invoke supersimmetry as the solution to the hierarchy problem. A robust and generic prediction of many of them is the existence of new particles, the top partners, again balancing the largest contribution to m_H coming from the top quark.

1.1.4 *The top partners*

Theoretical developments predicting the existence of top partners stem from the search for a way of introducing gravity in the SM, while solving the hierarchy problem at the same time.

Five-dimensional space-time theories including gravity can be formulated in terms of effective 4-d lagrangians where SM quarks mix with the top partners, which, again from naturalness arguments, should have a mass of the TeV scale. The lightest quarks have a small mass, indicating that their mixing with the new particles is small. The top quark, having a very large mass, should have a sizeable mixing with its partner, possibly making deviation from the SM top interactions detectable at the LHC.

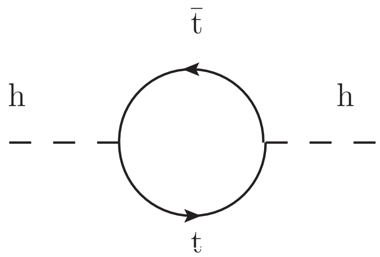

Figure 2: Radiative correction to the Higgs mass from the top quark.