Timon Mede

Statement of research

Jožef Stefan Institute,
Jamova 39
1000 Ljubljana,
Slovenia
✉ *timon.mede@ijs.si*

Introduction

Particle physics tries to understand the world at the smallest observable lengths. It is governed by two fundamental principles - quantum mechanical description of natural phenomena and special theory of relativity which together led to the formation of the quantum field theory. Recognition that all fundamental interactions can be identified with some gauge symmetry brought to the particular realization of this idea, which became known as the Standard Model.

Standard Model and Beyond

Standard Model is a phenomenologically remarkably successful effective theory of all particle forces but gravity at ordinary energies, based upon the $SU(3)_C \times SU(2)_L \times U(1)_Y$ gauge theory with spontaneous electroweak symmetry breaking at the weak scale ($M_W \simeq 10^2\,\mathrm{GeV}$) through the Higgs mechanism and a reasonably small number of free parameters. Its particle content consists of 3 generations of chiral matter (left and right handed quarks and leptons), 12 force carriers (gauge bosons) and a recently confirmed scalar Higgs field. And even though there is no convincing experimental evidence of additional structure up to TeV scale, there are some indirect theoretical reasons which point towards new physics, among others Standard Model predicts massless neutrinos, contrary to the neutrino oscillation measurements which show that at least 2 species of neutrinos are massive, it can not account for the dark matter in the Universe, the instability of the Higgs mass against the quantum corrections (the infamous hierarchy problem), unknown origin of the parity violation, the charge quantization accounted for by arbitrary U(1) quantum numbers due to the disparity of 3 different forces based on $SU(3)_C$, $SU(2)_L$ and $U(1)_Y$ gauge groups, ... Besides, at least at the Planck scale ($M_P \simeq 10^{19}\,\mathrm{GeV}$) where the gravitational interaction kicks in, such description becomes insufficient. These are the main reasons that motivate such fretful searches of the new physics beyond the Standard Model.

Supersymmetric Grand Unified Theories

One of the most promising attempts to tackle the physics beyond the Standard Model is based on the Unification paradigm which assumes that Nature can be explained by a single unified theory. In Grand Unified Theories (GUTs) strong, weak and electromagnetic interactions get unified at some high energy scale ($M_{GUT} \sim 10^{16}\,\mathrm{GeV}$). The theory is invariant under some single non-Abelian gauge group $\mathcal{G}$, which contains Standard Model as its subgroup and which then gets spontaneously broken down to it at the GUT scale through the Higgs mechanism ($\mathcal{G} \longrightarrow SU(3)_C \times SU(2)_L \times U(1)_Y$). Unification constrains some of the free parameters in the theory (masses, mixing angles, CP phases, ...), automatically guarantees charge quantization of all particles (not just thus far observed ones) and makes 2 generic beautiful predictions: proton decay (due to unification of matter) and the existence of magnetic monopoles (due to built-in quantization of electric charge).

Another important ingredient in the contemporary approaches to the high energy particle physics which gets nicely blent with the unification demand is supersymmetry. It is the only possible generalization of Poincaré symmetry and internal (gauge and global) symmetries. It gives us unification of gauge couplings at some high energy by itself, assuming just that all the superpartners of the Standard Model particles do not lie too far from the experimentally achievable TeV scale. The other motivation for its use is that it solves the hierarchy problem (cancellations of quadratic divergences) and in some cases, like R-parity conservation, provides a suitable candidate for the missing WIMP cold dark matter in the Universe. Because of its beautiful mathematical properties (e.g. small number of parameters - masses and couplings connected, non-renormalization theorem for superpotential, ...) it acts as a laboratory for ordinary field theories of particle physics. Supersymmetric transformation mixes bosonic and fermionic degrees of freedom within the supermultiplets, and those states should all have equal mass and other gauge quantum numbers (electric charge, weak isospin and colour degree of freedom). This is clearly not the case, therefore supersymmetry must be broken if it exists at all. Unfortunatelly the unknown mechanism of this breaking is a source of all sorts of ambiguities which greatly reduce the predictivity of such models. It turns out that it is not at all easy to spontaneously break supersymmetry, therefore we often parametrize our lack of knowledge of such mechanism with the soft terms that explicitly break supersymmetry, but in such a way that the solution to the hierarchy problem is still preserved. We must also impose some kind of a new (discrete) symmetry like R-parity to forbid the existence of B and L violating interactions leading to phenomenologically unviable $dim = 4$ contributions to proton decay.

Current work and future prospects

In our work so far we have shown that gauge symmetry and supersymmetry can be spontaneously broken by a single field in the superpotential (at the expense of fine-tuning of its parameters) without the use of gauge singlets or non-perturbative approaches. The metastable vacuum state was induced radiatively in the Coleman-Weinberg 1-loop effective potential of the single gauge non-singlet superfield by somewhat generalizing the Witten's mechanism for generating hierarchy between the weak and the GUT scale. The usual way is to stabilize the gauge and supersymmetry breaking tree-level flat direction by radiative corrections. Our method differs in that we do not expand the scalar potential around the tree-level extremum, but instead a minimum is induced in a region where the tree-level potential is almost flat and which can lie very far off tree-level minimum. Supersymmetry breaking is mediated to the observable sector through both gauge and chiral messenger loops, and because only a single field is needed, the dangerous tachyonic scalar masses due to the large negative 1-loop gauge messenger contributions are avoided. In the explicit example of the minimal supersymmetric SU(5) model with the addition of non-renormalizable terms the conclusion was that the Higgs color triplet mass can be increased, thus implying a stronger suppression of the $d = 5$ proton decay operators. On the other hand also supergravity contributions to the MSSM soft terms can become more important which reduces the predictive power of gauge mediation for the superpartner spectrum.

While building realistic supersymmetric unified models one can encounter various discrepancies with the phenomenological constraints: the vacuum stability issues, the possible appearence of the phenomenologically untenable light states that can spoil gauge coupling unification, the incorrect mass relations among light fermions, too fast proton decay, large flavour changing neutral currents, the neutrino masses and mixings, the unknown mechanism of mediation of supersymmetry breaking to the Standard Model sector etc.

Currently I am involved in a study of the structure of the minimal renormalizable supersymmetric SU(5) model spectrum that wouldn't contradict any of the phenomenological constraints mentioned above and at the same time reproduce the correct Higgs mass, respect all the LHC bounds on sfermion and gluino masses, keep the model perturbative and exhibit as little fine-tuning as possible. Exploration of the parameter space should answer whether the supergravity mediated minimal SU(5) scenario is still feasible (up to neutrino masses). This work should be ready for publication in the next month or so.

In the future I would like to continue my work on GUT models with a possible expansion to the field of neutrino masses and flavour physics. In this respect, I would find working together with theorists from

CFTP very stimulating and fruitful.

Publications

[1] B. Bajc, S. Lavignac and T. Mede, "Supersymmetry Breaking Induced by Radiative Corrections," JHEP **1207** (2012) 185 [arXiv:1202.2845 [hep-ph]]

[2] *work in progress* (estimated time of release: Mar 2013)