Statement of Research Interests

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Beyond Standard Model Physics

In my view, the ultimate goal of theoretical high energy physics lies in providing the description of the fundamental particles (or strings, if that is the case) and of the interactions between them.

While the Standard Model (SM) continues to successfully describe all existing data (when massive neutrinos are taken into account), there are sound theoretical reasons to believe that there is physics beyond the SM (BSM). Appealing extensions of the SM often include supersymmetry (SUSY), as well as more fundamental Grand Unified Theories (GUTs), such as an $SO(10)$ gauge group that would underlie the $SU(3) \times SU(2) \times U(1)$ gauge group of the SM.

My research interests all fit within BSM physics, particularly in Family Symmetries (FSs).

Within BSM, SUSY is quite appealing (from the theory point of view at least). It possesses four highly desirable features:

- provides the most compelling solution to the SM hierarchy problem.
- enables a tantalising unification of gauge couplings.
- presents a radiative mechanism that can drive the electroweak breaking.
- features dark matter candidates.

If SUSY is indeed realised in nature and provides a satisfactory solution to the SM hierarchy problem, we expect to observe it in the Large Hadron Collider (LHC). The experimental data will possibly allow us to establish which particular realisation of SUSY is the correct one.

I find it to be very timely to conduct research on SUSY phenomenology, and as a consequence, I am very interested in continuing to do so, particularly as the LHC accumulates data. I am specifically interested in models containing FSs, attempting explanations of the fermion masses and mixings; the SUSY flavour problem; and models containing GUTs.

Family symmetries

My main research interest is the origin of fermion masses and mixings (FMM). The question of why we have three generations of each type of fundamental fermion remains unanswered. In the SM the masses and mixings of the all these fermions are simply parameters (the Yukawa couplings) that need to be measured; but when going beyond the SM, the fermion parameters can arise through underlying mechanisms of a more fundamental nature - examples of such being the Froggatt-Nielsen mechanism or the Seesaw mechanism, mechanisms that generate fermion masses through higher-dimension operators involving heavier particles.

I consider particularly attractive (even if ambitious) to attempt simultaneous explanation of all the features displayed by the known fermions:

- three generations for all fundamental fermions.
- strong hierarchy in all the charged fermions, with a very heavy third generation.
- small mixing in the quark sector.

- tiny neutrino masses, when compared to the charged leptons (and particularly when compared to the quarks).
- the puzzlingly large, near tri-bimaximal mixing of the lepton sector.

Notably the last item, as observed from neutrino oscillation, is in stark contrast with the small quark mixing. As experiments make more precise measurements of the leptonic mixing angles, it is quite relevant to consider whether these intriguing observations are actually a signal of some underlying physics rather than accidental.

In my opinion, FSs provide the most promising approach to the study of this very important topic, and as such, I'm keenly interested in continuing research on FSs within the SM or extensions (such as in SUSY extensions of the SM).

While the prospect for confirming or constraining FS models is directly tied with improving measurements of leptonic mixing angles, there may be other observable consequences which would provide constraints for the models. In the context of FSs, the field content is extended and the extra fields may enable a varied range of detection possibilities. Arguably the most exciting case is the direct detection of particles explicitly carrying family charge at colliders (in the LHC or a future International Linear Collider), which can occur in scenarios where there is a sufficiently light pseudo-Goldstone boson associated with a discrete family symmetry. Other avenues include possible indirect hints of a FS, either in relation with cosmology (through mechanisms like Leptogenesis) or through rare flavour violating processes (such as flavour changing neutral currents), which continue to be searched in precision experiments, at dedicated flavour factories and also in the LHC (in LHCb).

SUSY flavour problem

Current precision tests of flavour changing neutral currents already provide indirect constraints on the sfermion masses. The experimental bounds seem to require a high degree of degeneracy in the sfermion masses, apparently requiring fine-tuning to satisfy them - this is the SUSY flavour problem.

There are three main ways of trying to solve this problem, namely through supergravity (SUGRA), gauge mediated SUSY breaking or by using FSs.

It continues to be relevant to consider in detail each of these frameworks, and how they can provide natural solutions to the SUSY flavour problem in varied SUSY extensions of the SM.

SUSY GUTs

With the hints of unification of gauge couplings found in SUSY models, it is often assumed that some kind of GUT will be valid at a high-energy unification scale. GUTs provide compellingly simple explanations for questions left unanswered in the SM, such as the hypercharge assignments of particles. It is quite striking that in $SO(10)$ models, all the fermions (including right-handed neutrinos) in each generation belong to the same fundamental multiplet. On the other hand, GUTs predict yet unobserved phenomena such as proton decay, which in simple models typically occurs at a rate already excluded by observation.

There have been many proposed SUSY GUTs extensions of the SM, and it continues to be an interesting and active area of beyond SM physics research. I find it particularly interesting to attempt to combine a GUT with a FS (thus explaining the three generations) in an simple, elegant way.

Secondary Research Interests

While my main research interest continues to be FMM and namely FSs, I am very interested in conducting research in different (but interconnected) areas, such as Cosmology (e.g. the topic of Leptogenesis), LHC / collider phenomenology (reach and detection possibilities) and even some specific topics of String theory (e.g. String-inspired GUT scenarios). I have particular affinity in updating and increasing my knowledge of Cosmology, having started my career as a researcher by studying it.

I believe that diversifying into one or more of the aforementioned areas will greatly benefit me as a researcher. As such I am interested in opportunities that encourage me to branch out to topics that I haven't studied in great detail before - more so when it is possible to combine said topics with my main research interest of FSs and FMM.