Research Area: Extensions of the SM – neutrinos and Higgses

The usual approach to construct the seesaw extension of the Standard Model (SM) adds three heavy Majorana fermions to the fields of the SM and constructs the seesaw effect individually for the three light neutrinos. The mixing of the neutrinos is then a phenomenological parametrization of the possible mass terms.

When we add only a single Majorana fermion there are less possible additional terms and the mixing of the neutrinos is restricted. This mixing is measured in the neutrino oscillation experiments.

The first task of any student is to learn the context: Lagrangian write-up of the SM and mixing of fields [1, 2, 3], neutrino oscillations and the seesaw mechanism [4, 5], and the meaning of a Majorana fermion [6].

The theoretical model we are working on, the Grimus-Neufeld model (GNM) [7], includes a second Higgs doublet [8, 9, 10], which allows the radiative mass generation for the neutrinos [11, 12].

An example of one task that a student could do: investigate the constraint on the neutrino mixing matrix from the assumption that only a single heavy Majorana field is added, considering [13].

Another task would be to investigate, how Lepton Flavor violating processes constraint the Yukawa couplings, extending the bachelor thesis of Aidas Petryla in 2017, now in the context of the GNM.

Another direction is the working out of specific aspects of the renormalisation procedure of the whole model [14].

Some of the not yet discoverd particles predicted by the GNM could be a dark matter candidate, which opens up thesis themes in Cosmology. Within Cosmology the concept of Baryogenesis explains, why we see matter around us, but not anti-matter. The GNM could model Baryogenesis via Leptogenesis, which is possible with CP violation in the Lepton sector. This gives the next area of possible thesis themes.

A large question is connected with a possible third Higgs doublet.

Since this model should also be tested, we have to think of calculating consequences, that might be seen in experiments. One theoretical step is the inclusion of the model into general tools that allow further theoretical predictions, like FlexibleSUSY [15, 16] or MadGraph [17].

Another direction of research is Machine Learning techniques for studying extensions of the Standard Model: Theoretical constraints such as unitarity (UNI) and bounded from below conditions (BFB) are important in model building, ensuring physical consistency and stability of the theoretical models. In recent work [18], Machine Learning (ML) techniques were employed to predict UNI and BFB constraints in multi-scalar models. It was demonstrated for the first time that ML offers a distinct advantage by enabling faster and precise calculations compared to alternative numerical methods in this field. The develop of ML techniques to optimize the numerical calculations of the models under study is another area of possible thesis theme.

In this theme many different specific thesis topics are possible, therefore it is essential that the respective student comes to discuss the interest before trying to read all the reference material!

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