Research statement

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My research interests lie in the phenomenology of a broad range of models beyond the standard model (SM) of particle physics. In spite of the great success of the SM, there remain many problems that cannot be solved within the SM. These problems include, for example, the existence of the dark matter (DM), naturalness of the electroweak (EW) scale, structure of the gauge symmetries, and origin of the quark and lepton families. To answer one or several of them, many models are proposed such as the minimally supersymmetric standard model (MSSM), grand unified theory (GUT), flavor symmetry, and so on. They often lead to some interesting phenomenology that can be used to distinguish them from the SM. I seek ways to test them using both a top-down approach where a model or its parameter space is constrained from theoretical consideration, and a bottom-up approach where the experimental search probes a new particle contained in a model.

Achievements so far

Since we now live in the EW vacuum, the requirement of the (meta-)stability of the vacuum can be used to test and constrain models in a top-down approach. This approach is powerful because it can probe new particles that are too heavy to be accessed using any ongoing or planned experiment. Also, this approach is applicable to many models that contain some additional fields and/or couplings to the SM Higgs boson. During the last few years, I have been developing the next-to-leading order calculation of the decay rate of the EW vacuum ([1,8,9] of my publications). My treatment filled a gap of existing calculations and enabled us to precisely evaluate the decay rate with error estimations. I analyzed not only the SM but also models with new particles that couple to Higgs and obtained severe constraints on their couplings and masses.

It is also important to use the collider experiments as an example of the bottom-up

approach. In particular, recent hadron colliders provide a huge amount of data, under which a hint of the new physics may be buried. To fully use the data, it is necessary to develop a proper physics quantity or a wise way to extract the signal of a new particle. I have adopted several ways to tackle this difficult problem. So far, I mainly focused on the search for massive particles with EW charges (EWIMPs) that are good DM candidates appearing in many well-known models such as the MSSM using the future hadron colliders. When the charged component of an EWIMP is long-lived, the disappearing track search is useful to reduce background events. I collaborated with several experimentalists and seeked a possibility of using track information to fully reconstruct the event kinematics and to determine the masses of new particles [4]. On the other hand, for some EWIMPs such as the Higgsino-like state in the MSSM, the charged component is short-lived and the track information is not available. To handle this case, I focused on the lepton pair production process that is affected by EWIMPs at the one-loop level and developed a way to use the signal shape to reduce the systematic uncertainties. As a result, I obtained the best limit so far for Higgsino [3,5].

It is another interesting way of research to build a new physics model. All problems in the SM are hints of the theory of everything, which is our ultimate goal. By providing simple solutions to them, we can enrich our knowledge about what could be there beyond the SM. In several works, I focused on discrete flavor symmetry and GUT models that provide a unified description of SM fermion families and gauge symmetries, respectively. In models with spontaneously broken discrete symmetries, domain walls may be formed that will eventually dominate the energy of our universe. To avoid this problem, I constructed several models with discrete flavor symmetry [2,6,7] in which cosmological dynamics does not lead to the formation of the stable domain wall and the most recent observation of the neutrino mixing angles are correctly predicted at the same time. In the projects about GUT models [10,11], I focused on the supersymmetric SU(5) GUT and looked for the parameter space where the unification of the Yukawa coupling constants, which is the prediction of the model, is achieved. I also considered the effect of extra matter fields by calculating their

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contribution to the renormalization group equations and found some parameter space that gives a consistent prediction.

Future plans

Now it is an exciting time with many ongoing and future planned experiments that provide a huge number of hints of the new physics. The results of these experiments will guide future theoretical works. At the same time, a great deal of effort is devoted to developing new approaches to the problems of the SM and new techniques to extract the information from experimental results. As a young researcher at this time, I am eager to engage in fields of great progress and to keep seeking a trace of the new physics.

Recently, we have made significant progress in developing techniques that enable us to systematically analyze the collider data. These include, for example, the effective field theory (EFT) and machine learning. One possible way is to consider how to use them to enlarge the reach of the collider experiments.

The EFT technique is also useful for the evaluation of the event rate in DM direct detection experiments. Since there are numerous models with a broad range of DM mass in the literature, I will try to obtain some systematic treatment applicable for many models and to suggest new experiments for the mass region unconstrained so far.

Another possibility is to extend my works in a top-down approach. Calculation of the EW vacuum decay rate in complex models with several scalar fields involved in the bounce will be particularly important due to its broad applicability. I will also consider how we can take into account the thermal effect and effect of gravity both of which may drastically change the situation.

After all, the fields of great interest highly depends on the future development of the calculation technique, appearence of new ideas, and results of experiments. To keep track of the latest trends, I will not restrict myself to studying the same subjects as I have been involved in and have a wide field of view during my research career.