Research statement

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My research interests lie in the phenomenology of broad range of models beyond the standard model (SM) of the particle physics. In spite of the great success of the SM, there remain many questions that cannot be answered within the SM. These questions include, for example, the structure of the gauge symmetries, the existence of the dark matter (DM), origin of the quark and lepton families, and naturalness of the electroweak (EW) scale. To give an answer to one or several of them, numbers of models are proposed such as the grand unification, minimally supersymmetric extention of the SM (MSSM), family 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

Many models contain some additional scalar fields and/or coupling to the SM Higgs boson that affect the stability of the EW vacuum. Requirement of the (meta-)stable EW vacuum can be used to test and constrain models. During the last few years, we have been developing the next-to-leading order calculation of the decay rate of the EW vacuum (please see [1,8,9] of my publication list). We assumed that the SM Higgs is the unique scalar particle in the model and provided a correct treatment of the flat direction of the Euclidean action related to the approximate classical conformal invariance of the potential. This treatment filled a gap of the existing calculation and enabled us to precisely evaluate the decay rate with error estimations. We analyzed not only the SM but also several models with new particles that couple to Higgs and obtained severe constraints on the coupling and mass of new particles even for the mass region much heavier than the TeV-scale.

As for the collider search, massive particles with EW charges (EWIMPs) are interesting targets that often appear in models since the TeV-scale mass is predicted from the relic abundance of the DM neglecting the non-thermal production. Recently, we have worked on the EWIMP search and measurement of its properties using future hadron colliders (please see [3–5]). In particular, we focused on EWIMPs with short lived charged components such as the Higgsino-like state in the MSSM. Since the tracker information cannot be used in this case, instead we considered the vacuum polarization effect from the EWIMP loop and its effects on the lepton pair production process. We revealed that the energy dependence of the loop effect possesses a characteristic shape with a sharp peak and used this shape to distinguish the signal from the background and effects of systematic errors. As a result, we obtained the best limit so far for the short lifetime Higgsino and revealed that the signal shape can also be used for measurement of the coupling and mass of discovered EWIMPs.

Future plans

In the near future I will extend our calculation of the vacuum decay rate to the models with several scalar fields involved in the bounce configuration. This allows us to evaluate the vacuum decay rate in various complicated models such as the MSSM, and to constrain the parameter space even when the relevant scalar particles are beyond the experimental reach. For the generic models with several mass scales, the multi-scale nature of the bounce makes the numerical calculation difficult. Therefore, another possible future direction is to develop an algorithm to adaptively adjust the lattice spacing for the fast and accurate computation.

Regarding the collider phenomenology, I will apply our method to the pair production process of gauge bosons. This gives us a severer bound on the Higgsino that may reach the mass prefered from the DM relic abundance. Another possibility is to study loop topologies different from the vacuum polarization. Through the classification of the signal shape for each loop topology, it will become possible to find new particles to which our detection method can be applied. Finally, the future planned lepton colliders such as ILC and CLIC also bring us some exciting possibilities. Since they provide more precise measurements in lower energy scale compared with hadron colliders, it will be efficient to analyze the new particles effect using the effective field theory approach. I will provide some model-independent constraints on EWIMPs through the precise measurement at lepton colliders.