Research Statement

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My current research concentrates on Large Hadron Collider (LHC) phenomenology, especially that related to Higgs physics and dark matter. The phenomenology of the 125.5 GeV Higgs boson, which was discovered at the LHC, in the next-to-minimal supersymmetric standard model (NMSSM) and two-Higgs-doublet model (2HDM) has constituted the main part of my work towards my Ph.D. degree. I am in the process of expanding my research work to include the topics of extra dimensions and inflation of the early universe.

Accomplished work

We first assessed the extent to which various semi-constrained NMSSM (scNMSSM) scenarios with a $\sim$125 GeV lightest CP-even Higgs h_1 are able to describe the LHC signal. We found that enhanced $\gamma\gamma$ rates are most natural when the h_1 has mass similar to the second lightest CP-even Higgs, h_2, with enhancement particularly likely if the h_1 and h_2 are degenerate. To experimentally probe this possibility, we developed diagnostic tools that could discriminate whether or not there are two (or more) Higgs bosons versus just one contributing to the LHC signals at 125.5 GeV. In addition, we considered the case where the lightest Higgs h_1 provides a consistent description of the small LEP excess at 98 GeV whereas the heavier Higgs h_2 possesses the primary features of the LHC Higgs-like signals at 125 GeV.

Besides the NMSSM studies, the 2HDM, one of the simplest extensions of the Higgs sector, is another focus of my research work. We recently performed an exhaustive analysis for Type I and Type II models to address an important question: to what extent are the latest measurements of the 125.5 GeV Higgs-like signal at the LHC compatible with the 2HDM, assuming that the observed 125.5 GeV state is one of the two CP-even Higgs bosons? We also discussed the implications for future colliders, including expectations regarding other lighter or heavier Higgs bosons. In an earlier study, we examined the maximum Higgs signal enhancements that can be achieved in the 2HDM in which either a single Higgs boson or multiple Higgs bosons have mass(es) near 125.5 GeV. We found that the constraints requiring vacuum stability, unitarity and perturbativity substantially restrict possibilities for signal enhancement.

Furthermore, we extend the 2HDM by adding a real gauge-singlet scalar (2HDMS), which could be stable under the extra $\mathbb{Z}_2$ symmetry and thereby a possible dark matter (DM) candidate. Comparing with the simplest singlet extension this model has richer phenomenology. For heavy DM (mass above 55 GeV) which generates the desired relic abundance, the predicted cross section for DM-nucleon scattering is below the current LUX limit and even the future XENON1T projection. In contrast, this model can accommodate light DM, even if the constraint on Higgs invisible decay is taken into account, and describe the CDMS II and CoGeNT positive signal regions. More impressively, the tension with the LUX/SuperCDMS exclusion can be alleviated in the Type II 2HDMS in which the DM-nucleon interaction could be isospin-violating. In the process of completing this project, we independently worked out the model files for the FeynRules program and will make the model database publicly available soon.

Ongoing projects

Based on the comprehensive studies we have accomplished, we focus on the light (pseudo)scalar Higgs boson region in the 2HDM. We are also pursuing whether the current LHC 8 TeV-run data pushes the 2HDM to the alignment limit and/or the decoupling limit. In the meanwhile we are developing a routine to simplify the calculation for gluon-fusion and bottom-quark associated production cross sections. Besides, we consider the decoupling 2HDM to determine if the vacuum could be stable above the inflation or GUT scale, assuming the 2HDM is a low-energy effective theory. If it is stable, then the inflation driven by the 2HDM Higgs would be possible and a topic for future study.

One of the most important extensions of the standard model (SM) is the inclusion of additional particle(s) that comprise the DM of the universe. So far a number of collaborations have been devoted to working on the direct detection of DM. They typically translate the limit on the event rate against recoil energy they directly detect into a limit on the DM-proton cross section as a function of DM mass. However, there are several standard assumptions hidden in this translation that might not be correct. In particular, it is normally assumed that DM has equal coupling to neutrons and protons. In fact, the tension between the null LUX/SuperCDMS exclusions and the positive signal regions favored by CDMS II and CoGeNT could be alleviated if the DM interactions with nucleons are allowed to violate isospin symmetry. Thus, we are now interested in exploring the possibilities of a light isospin-violating DM (IVDM) in the 2HDMS and NMSSM even though such an isospin-violation effect in supersymmetry (SUSY) models has been claimed to be negligible. If present, such light annihilating IVDM may explain the origin of the excess of gamma ray flux from the galactic center, as indicated in the previous studies.

Another project I am now involved in is warped DM. In view of the success of extra dimensions in resolving the hierarchy and flavor problems of the SM, we are studying DM in warped extra dimensions in particular with Randall-Sundrum like geometries. We consider the case that all SM fields live in the bulk. In our model the first Higgs excited state is a possible stable DM candidate due to the presence of a geometric KK-parity. Our focus is on phenomenological implications of the DM after imposing constraints from current experimental data.

Future plan

In the near future I will continue investigating LHC implications of various Higgs models beyond the SM both within and outside the framework of SUSY. Potential extensions to my previous studies include the future prospects of 2HDM at the 100 TeV collider and the related analyses in the framework of phenomenological NMSSM, a version of NMSSM without GUT-scale unification assumptions. Additionally, dark matter physics and inflation of the early universe driven by the Higgs boson, Higgs portal DM, axion, etc. will be important topics of exploration in my post-doctoral research. It is well-known that Higgs inflation is unlikely to occur within the pure SM given the latest LHC measurement on the top quark mass. To remedy this issue, I am considering the additional loop contribution from Higgs portal interactions to raise the tensor-to-scalar ratio at the inflation scale. Another probable direction of my future work is in Higgs triplet and neutrino physics. I wish to construct a model that contains a LHC observed Higgs and a DM candidate and is also able to explain the neutrino mass by means of Type-II seesaw mechanism.

Rather than being the end of the story, the discovery of the 125.5 GeV Higgs boson has marked a new era in particle physics. I anticipate that this discovery will provide a key window into theories beyond the SM, and that additional Higgs bosons and SUSY particles may well be found. A variety of ongoing experiments aimed at detecting dark matter will either provide further limits or succeed in detecting dark matter. Either way, DM models will be constrained and/or eliminated, thereby providing guidance to ongoing theoretical work. As a young researcher, I am fortunate to be in the midst of an exciting time and will certainly work extremely hard to contribute to our high energy physics community.