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Testing new theories using precise calculations of Higgs particle properties

Summary for general public

It seems odd to be even asking the question “Why do elementary particles have mass?”. Surely it is just a property of the particle itself, is it not? Unfortunately, as it is often in science, the answer turns out to be more complicated. While in some cases it indeed can be a particle’s intrinsic property, such model would not describe the Universe we are living in. The theoretically consistent model explaining why particles we observe have masses and interact in the way they do has to rely on something else. This model, developed by Glashow, Weinberg, Salam (GWS) and others in the 60s, uses the Brout-Englert-Higgs (BEH) mechanism of spontaneous symmetry breaking as the explanation of how elementary particles “acquire” mass. The BEH mechanism postulates the existence of the Higgs field which, interacting with observed particles, effectively generates their mass. The consequence of that mechanism is also the existence of a new particle, the so called Higgs boson.

The GWS model together with the Quantum Chromodynamics forms the Standard Model (SM) of elementary interactions – the current basis of all of the particle physics. The discovery at the Large Hadron Collider (LHC) of its last missing, predicted element – the Higgs boson – was announced in 2012. Nevertheless, experiments and theory suggest, that this is not the end of discoveries in particle physics. To name only a few outstanding problems: most probably 23% of the energy content of the Universe is in the form of some yet unknown particles; neutrino masses also do not have a compelling explanation within the Standard Model and theoretical arguments concerning the BEH mechanism itself suggest that the Standard Model should be treated rather as an effective description of known particles – not as a fundamental theory. Hence the goal behind the LHC was not only to discover the Higgs boson (which was widely believed to have existed), but also to discover new fundamental particles that would lead us to the so called Beyond the Standard Model (BSM) theory. The latter has not happened.

Even despite the very successful (from the technical point of view) operation of the LHC, since 2012 we were unable to find any new elementary particles. And even though the LHC will operate for the next 15 years, without increase in its collision energy it is plausible that no direct signal of BSM physics will ever be observed there. In such case, the physics output of the LHC will be the more and more precise measurement of the properties of SM particles – especially the Higgs boson. While it seems less exciting than discovery of a new particle, it does not have to be so. One should remember that a lot of BSM theories are proposed as the solution to remaining theoretical problems of the BEH mechanism. Such theories would naturally leave their mark on the properties of the Higgs boson we have discovered. And through it, we can study them.

The main goal of the project is therefore to study BSM physics though the prism of Higgs boson properties, where two most important ones are its mass and its decay patterns. Being able to predict the correct Higgs boson mass is one of the strongest constraints on a BSM model. Here theorists have made great progress in recent years. Additionally the Higgs boson is unstable, and once produced decays with a pattern that can be predicted by a theory. So called branching ratios, that is how often does a particle decay to a particular final state, are an important experimental observable. This is what this project will focus on. By precisely predicting decay patterns of the Higgs boson in BSM theories we can either rule out a model or propose a way to look for it. Though unsurprisingly, precise predictions are difficult. To draw any meaningful conclusion about a BSM model from the LHC and the future High Luminosity LHC, the calculation should have an accuracy better than 5%. Doing such precise calculation for every single BSM model of interest to physicists is a daunting (and more important error prone) task. For that reason the first goal of the project is to automatize such computations in an arbitrary BSM model, with precision sufficient not only for current but also for future collider experiments. This will require technical expertise in implementing such processes as well as new theoretical insights. For example, the calculation should be organized in a way that minimizes remaining theoretical uncertainties. Having at hand a tool allowing for high precision calculation of Higgs boson decays will then allow to proceed with phenomenological studies of interesting BSM models.

In the end, the outcome of the project will be the analysis of constraints on less studied BSM models coming from the Higgs physics. While more often studied models are getting severely constrained by the data it is necessaries to look beyond them. New models are also important in the context of present and upcoming low energy experiments like the ongoing muon g-2 measurement at Fermilab. For example, the confirmation of the deviation from the SM announced this year by Fermilab should ideally be connected with Higgs physics in a full, realistic model.

In summary, for the foreseeable future the Higgs boson could be one of our only few windows to the Beyond the Standard Model physics. We need to do whatever we can to open it.