Research Statement

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Introduction

The standard model (SM) of particle physics has been tested to an extremely high degree of accuracy, reaching its high point in the precision measurements at the CERN e^+e^- collider LEP. However, the bosonic sector of the SM is not complete, the Higgs boson is yet to be found. A direct experimental demonstration of the Higgs mechanism of the fermion mass generation still does not exist. Thus the discovery of the Higgs boson, a study of its properties and the subsequent study of electroweak symmetry breaking (SSB) mechanism is one of the prime aims of all the current and next generation colliders.

Even after a great experimental success, the SM suffers from some theoretical problems such as : instability of the Higgs boson mass against radiative correction, hierarchy of the fundamental scales, hierarchy in the masses of fermions, mechanism to break the electroweak symmetry, mechanism of CP violation etc. Some or all of these problems are addressed in various models of physics beyond the SM, such as models with extra-dimensions, with supersymmetry, or with other additional symmetries. Each of these model invariably propose new heavy particles that can potentially be produced at the upcoming LHC. Thus LHC will be a usefull machine to distinguish among the various models of new physics.

Approach

Most of the approaches towards new physics has been *top-down*, i.e. model building beyond the SM respecting the existing experimental bounds and addressing various issues listed in the previous paragraph. The merit of this approach is that it provides mechanism to address/solve the problems with the SM. However, the possible demerits are : it may not be a *testable* theory, it may have a rich spectrum with many free parameters, it may bring some more un-solved problems than it has solved etc. Another approach to new physics is *bottom-up*, i.e. phenomenological model building based on fundamental symmetries and experimental data. Though this method may not give a first principle understanding of the underlying phenomenon, it provides one with enough inputs to constrain/direct the *top-down* approach.

Unlike the *top-down* approach, the issues of pure theoretical nature are of very less or no importance in a *bottom-up* approach. For example, even the renormalizibility of the corresponding Quantum Field Theory (QFT) is not a requisite. Usually the new particle or interaction of interest is parameterized in terms of additional couplings and form-factors. Then one constructs a set of observables and develops a strategy to measure the proposed couplings, which in certain limits may imitate the SM scenario. The task here is to look for as many observables as possible, which can be constructed at a given collider. And then use them in a strategic way to extract maximum information about the underlying dynamics. Some of the observables are of very generic types and can be used for different colliders and processes, while some are very specific to either the collider or the process or both. I have worked on some observables, like asymmetries sensitive to polarization of top-quark, which can be used at all the colliders in any process of top quark production process. While some other observables, as simple as forward-backward asymmetry, may not be available at symmetric collider, such as LHC and PLC. Thus the strategy part of the analysis very much depends upon the choice of the collider, process and, of course, the nature of the new physics phenomenon one is looking for.

Since the Higgs boson of the SM is not yet discovered, the phenomenon of electro-weak symmetry breaking may, in principle, be more intricate than what is suggested in the SM. Further the top-quark mass is very close to the electro-weak scale, leads to the possibility of it having a large sensitivity towards new physics of electro-weak symmetry breaking. Thus top quark processes are most important for new physics studies.

Top quark : a looking glass

The top quark is very heavy and hence decays much before hadronization. Thus its spin information is translated into the kinematical distribution of its decay products. At the same time its decay width is very small as compared to its mass leading to a sharp resonance, which helps reducing the backgrounds. This also makes it possible to use *narrow width approximation* and simplify the calculations. With the use of narrow width approximation it has been shown (by me and collaborators) that the angular distribution of the decay leptons from top quark is insensitive to the anomalous contribution to the tbW vertex in all processes of top quark production at all colliders. Hence the lepton distribution is sensitive only to the distribution and polarization of the produced top quarks, which is decided by the production dynamics. Thus, use of lepton distribution provides us with a tool to look at possible new physics in top quark production process without any contamination from possible new physics in the decay process. This result is modified only at *per mill* level due to radiative correction, hence a very useful observable for a *bottom-up* approach.

The only drawback in using lepton distribution is the low branching ratio of W boson into leptonic channel. This can potentially be improved by use of down-type light quarks in place of leptons. This, however, has two problems : the charge determination of light quarks is not easy and the radiative correction to the above mentioned "insensitivity" can be as large as 7% in the hadronic channels. The possibility to use hadronic channels is under investigation. These distribution are a tool to measure the polarization of the top-quark with a high accuracy and can be employed to analyze CP-violating or P-violating interactions.

P/CP violation

The phenomenon of CP violation is expected to appear in possible new physics as required by the baryon asymmetry of the Universe. The *bottom-up* approach mentioned above includes CP violation. Further, in many cases, CP observables involve the polarization and/or spin correlation of some of the particles. This requires the measurement of polarization of fundamental particles wherever possible. The polarization of τ-lepton has been studied in detail and I have worked on possible measurement of top quark's polarization using as simple observables as possible. These observables are employed to study CP properties of various interactions in a simple and feasible way. The azimuthal distribution of secondary lepton from decay of top quark is sensitive its polarization. It has been used to probe Higgs boson interactions at PLC and also the interaction of KK-excitations in various extra-dimension models, which have a P-violating interaction. In fact, using lepton-polarimeter for top quarks it is possible to study heavy, neutral resonances in $t\bar{t}$ and distinguish between various model candidate, such as ADD model, RS model, little Higgs model, technicolor models etc.

The polarization is an additional parameter that can be tuned for initial beams and can be measured for some of the final state particles. This additional parameter is very useful in providing additional information and in some cases simply magnifying the sensitivity. I have studied the role of longitudinal and transverse beam polarization at LC for Higgs boson and triple gauge boson couplings. It turns out that when it is not possible to study the polarization of the produced particles (by means of kinematical distribution) then one can use beam polarization and measure the same physical quantities in terms of simple kinematical distributions. A strategic combination of different initial state polarizations, longitudinal and/or transverse, is instrumental in giving otherwise unattenable informations.

Markov-Chain-Monte-Carlo

In the *top-down* approach to new physics the most prominant models are Minimal Supersymmetric Standard Model (MSSM) and warped extra dimension model like Randal-Sundrum (RS). Both this models receive constraints from the existing collider data and also from B-physics observable and cosmological observations. It is thus instructive to know the parts of parameter space of these models that comply with the existing constraints. To this end, recently, I have been working on constraining phenomenological MSSM by low energy observables, electro-weak precision observables in a Markov-Chain-Monte-Carlo approach. The next step in this analysis will be to look for the (possibly correlated) collider signature of the constrained parameter space. A similar study has also been performed for the RS model using a very small set of collider observables. A more elaborate study of the RS parameter space using MCMC method is still lacking and it requires a fair bit of research to *set-up* such an analysis.

Spin measurements at colliders

The MSSM and the extra-dimesional models compete with each other not just in providing the explaination to the un-resolved issues with the SM but also in having almost identical collider signature for many of its prominant processes with only difference being the spins of the particles involved. It is thus very important to have method to measure the spins of the particles at hadronice colliders like LHC. I have worked in this direction and have found a set asymmetries that can help one assess the spins of the particle if the momentum of the particle is reconstructed. This, however, is not always the case for the various processes at LHC in either MSSM or RS models. More methods need to be discovered and I am actively persueing this line of research.

Bottom line : In the *bottom-up* approach to new physics the polarization studies and use of beam polarization at LC and PLC are very useful in characterization of new particles and the polarization studies at LHC is very useful to distinguish among various new physics models. To this end, recently, I have been working on spin/polarization measurment of heavy particles and constraining phenomenological MSSM by low energy observables, electro-weak precision observables in a Markov-Chain-Monte-Carlo approach.