Glimpse into self-interaction of Higgs boson

The Higgs boson (H), discovered in 2012 by the ATLAS and CMS experiments, is the pinnacle of the scientific results obtained so far from the CERN-LHC. All the fundamental particles, known till now, gets their intrinsic mass via interactions with H and the interaction strength determines the mass of the particle. The large hadron collider (LHC) in the dominant avatar, is the facility where protons having energy 6500 times that of its mass (1 GeV or giga electron-Volt in the parlance of high energy physics) are smashed head-on 40 million times per sec at few interaction points along the circular path. The consequence is the occasional recreation of the environment similar to which existed in the universe within pico- to micro-seconds after its creation. Scientists, equipped with extremely complex detectors (read 100 million electronics channels, taking digital snapshots of the aftermath of the collision), sift through petabytes of data to pick up the most interesting and relatively rare events to unravel the mysteries of the universe at the most fundamental level (at the distance scale of nano-nano-meter). Using proton-on-proton collision data collected during LHC operations, the properties of the Higgs boson are being studied in minute detail by a large community of high energy physicist. The experimental measurements are compared with predictions from the standard model (SM), to vindicate it or to look for hints of physics beyond SM, nature of which is yet unknown. Precise measurements of its couplings to vector bosons (W or Z) and Yukawa couplings to heavy fermions have provided a strong indication that the mechanism of Electroweak Symmetry Breaking is similar to the one proposed by Brout, Englert and Higgs (BEH) about 50 years ago. The Physics Nobel prize in 2013 was awarded to F. Englert and P. Higgs. The SM also depicts H interacting with itself due to which 3 or 4 of them may couple via a single vertex. The strength of this self-coupling λ, in turn, determines the shape of the Higgs potential which has a considerable impact on our understanding of the properties of the very early universe and its future. Consequently, the measurement of λ is one of most important aspects of the LHC physics programme in recent years.

Figure 1 illustrates some of the possibilities of Higgs self-interaction at the LHC, where λ can be estimated by measuring the rate of diHiggs (HH) production i.e., the cross section of the process. Any deviation of the result from the SM prediction will be a hint of new physics at play; eg., the presence of physics beyond the SM can enhance the HH production rate by several orders of magnitude. Using proton-on-proton collision data at centre-of-mass energy of 13000 GeV and collected by CMS experiment during 2016 through 2018, the CMS international collaboration recently derived the best constraint on the value of λ to date. The inclusive final state considered by a group of scientists consisted of at least a pair of photons and a pair of hadronic jets initiated by b quarks arising due to the independent decays of 2 Higgs bosons, mainly due to the interaction of 2 gluons from the incoming protons and involving HHH vertex (Fig.1, left). The team included our Ph.D. student Shri Soumya Mukherjee and Prof. Kajari Mazumdar, who focussed in parallel, on a different and a specific production mode indicated by presence of 2 additional light quark jets in the final state and satisfying a set of particular topological criteria; here one of the constituent quarks of the initial proton from each incoming beam emits on the fly, a W or Z boson simultaneously; these fuse subsequently to produce a pair of Higgs bosons either directly (WWHH vertex) or via a HHH vertex involving λ (Fig.1, right). Accounting for this second type of HH production in data, for the first time by the LHC experiments, improved the sensitivity of the overall analysis. Using several innovative strategies compared to earlier analyses and applying multiple machine learning algorithms to identify the photons, the b jets as well as the signal-like events to discriminate the overwhelming background of similar final states due to other processes, the combined analysis from CMS produced the best results to date. Fig. 2 presents one of the distributions (invariant mass of 2 selected photons) derived from data interpreted in terms of resonant signals due to both double Higgs and single Higgs production (shapes determined from simulation) riding over continuum spectrum due to background processes (shape determined in a data-driven method) where the photons are uncorrelated. Categorizing the events according to specific properties of the signal increases the overall power of the analysis. The production process being very feeble there is significant statistical uncertainty in the inference, but anomalous effects resulting in much higher rate of HH production has been upended at the level of maximum about 7.7 times the rate of cross section predicted by SM, at 95% confidence level. This, in turn, translates into the derived λ value to be SM-like. Taking ratio with SM value the coupling strength in data is measured to be $0.6^{+6.3}_{-1.8}$ at 68% confidence level . The analysis also ruled out a large part of parameter space defined by various possibilities of beyond SM physics.

These results are extremely encouraging to pin down the nature of H. The LHC experiments are poised to actually “observe” the Higgs pair production with better confidence in the near future. The LHC machine is scheduled to deliver data again starting 2022.

Shri Soumya Mukherjee presented these results recently, for the first time, to the international high energy physics community in an international conference on behalf of the CMS collaboration. The paper has been submitted to the Journal of High Energy Physics and has appeared on the web on 26.11.2020 as referenced below.

References: https://arxiv.org/abs/2011.12373

CMS Collaboration,"*Search for nonresonant Higgs boson pair production in final states with two bottom quarks and two photons in proton-proton collisions at sqrt(s)=13 TeV*"

Fig. 1: Representative Feynman diagrams depicting fundamental interactions of the constituents of protons (quarks and gluons) to produce a pair of Higgs bosons at the LHC.

Fig.2 The weighted diphoton invariant mass distribution for the selected ɣɣbb events. The red line includes the observed HH signal contribution, while the blue line represents the contribution from background processes only.