Indian Institute of Technology, Kanpur

PHY690B : Physics at Large Hadron Collider

1. **No. of Lectures per week: 3 (L), Tutorial: 1 (T), Laboratory: 0 (P), Additional Hours[0-2]: 0 (A),**

   Credits (3*L+1*T+P+A): 11 Duration of Course: Full Semester

2. Proposing Department/IDP : PHY.

   Other Departments/IDPs which may be interested in the proposed course: NA

3. Proposing Instructor: Sanmay Ganguly (PHY)

4. **Course Description:**

   A) Objectives: This course is intended for students who are willing to learn the broad aspects of physics at Large Hadron Collider. This will cover basics of Quantum Chromo Dynamics, I.e., matrix elements, parton-shower, hadronization, jet physics and parton distribution functions. This will be followed by numerical simulation of these processes using MadGraph, Pythia, FastJet, Delphes and ROOT. The second part of the course will cover in details object reconstruction like electron photons and jet by combining different parts of the detector components like Electromagnetic and Hadronic Calorimeter and Tracker. The third part will cover Higgs related measurements and its nitty-gritty at LHC. The fourth part of the course will discuss broader aspects of new physics searches at LHC and what are the prospects of HL-LHC.

   B) Contents:

S. No.	Broad Title	Topics	No. of Lectures
	Perturbative QCD	The parton model, leading scattering processes, infrared and collinear safety, hadronization, jet formation and jet reconstruction algorithms, jet substructure variables and their properties, running of strong coupling constant, parton distribution functions.	**8**
	Simulation and simulators in collider physics	Introduction to different matrix element simulators like Pythia, Herwig, Powhegbox and their qualitative comparisons. Hands on coding to Madgraph and run a full simulation chain with Delphes detector simulation. Jet reconstruction and studies using FastJet.	**10**
	Object and event reconstruction in HEP	Introduction to basic object reconstruction in experiments like electron, photon, hadrons and jets. Introduction to global event reconstruction techniques like particle-flow algorithm.	**8**
	Design and implementation of a measurement at LHC	Given a physics task like measuring Higgs boson mass or coupling, how an analysis strategy is designed based on individual final states, estimation of signal and background and finally the statistical analysis to extract the parameter of interest, will be discussed in details. Will use LHC open data.	**8**
	Design and implementation of a new physics search at LHC	We will walk through a model specific search. Then will show how keeping the same final states, one can play with the statistical fit model to do different theory interpretations.	**4**

	Future directions of collider physics	Discussion on novel signatures and interesting physics goals for immediate future and HL-LHC. Also a general overview of proposed collider programs and their physics reach for precision measurements as well as BSM physics search	**2**
		Total number of lectures:	**40**

C) Pre-requisites**: Familiarity with the contents of PHY 680, PHY 681 and PHY 683 will be helpful (i.e. you are expected to be able to write down the amplitude of a tree level Feynman diagram). Working knowledge of C++ and Python will be advantageous.**

D) **Short summary for the Courses of Study Booklet:** Large Hadron Collider was designed to figure out how unitarity of Standard Model of particle physics is preserved around electroweak scale and it has answered it by discovering the Higgs boson. The search for how nature looks like at the shortest length scale is still going strong. In this course we will try to learn how all these are done at a technical level by going through the theoretical background, experimental reconstruction techniques and statistical analysis.

7. Recommended resources:

1. Lecture on LHC Physics, Tilman Plehn. Springer Lecture Notes in Physics, volume 886.
2. Quantum Chromodynamics: High Energy Experiments and Theory. Gunther Dissertori et al. OUP 2003.
3. The Black Book of Quantum Chromodynamics : A primer for the LHC Era. John Campbell et al. OUP 2018.
4. Looking Inside Jets : An Introduction to jet substructure and boosted-object phenomenology. Simone Marzani et. al. Springer Lecture Notes in Physics.
5. QCD and collider physics, Ellis, Sterling, Weber. Cambridge University Press.
6. Madgraph School, CTEQ school, TASI audio visual contents, MITP, GGI YouTube channels.
7. CMS and ATLAS public webpages.
8. Anatomy of Electroweak Symmetry Breaking. Part-1 (hep-ph/0503172) and Part-2 (hep-ph/0503173).
9. Higgs Hunter's Guide. John F. Gunion et al.
10. Collider Physics Within Standard Model : A primer. G. Altarelli & J. Wells