

PHD PROGRAMME IN PHYSICS, ASTROPHYSICS, AND APPLIED PHYSICS
UNIVERSITÀ DEGLI STUDI DI MILANO
PhD Cycle 41 (2025-2026)

All lectures will be given in English.

Course title	Computational, simulation and machine-learning methods in high-energy physics and beyond. Automated computational tools
Teacher in charge of the course	Carrazza Stefano
List of the teachers of the course	Zaro Marco, University of Milan, marco.zaro@unimi.it Winterhalden Ramon, University of Milan, ramon.winterhalder@unimi.it
Training objectives	After the course, the student will know: - the algorithms employed to compute an arbitrary amplitude automatically. - Monte-carlo techniques to efficiently perform numerical integration - the concept of infra-red safety, and how to apply it to kinematic observables - the basic mechanism of a parton shower, and the meaning of the Sudakov form factor - how infra-red singularities arise in higher-order computations, and how to deal with them at NLO. In particular, local-subtraction methods - the meaning of, and the usage of, matched/merged computations - the usage of softwares like MadGraph5_aMC@NLO for the automatic computation of amplitudes and their integration
Prerequisites	Quantum-field theory, in particular the phenomenological aspects related to the Standard-Model. Computation of simple amplitudes and cross sections by means of Feynman diagrams. Special relativity. This knowledge is required for the course
Detailed course program	Anatomy of scattering cross sections, at tree level - amplitude computations using Feynman diagrams and helicity routines - numerical integration techniques. From one to multi-dimensional. Multi-channeling and variable transformations - How to include/exclude certain classes of Feynman diagrams, and the problems related with doing so Parton-shower and multi-jet merging - Collinear approximation for multi-particle amplitudes - Splitting kernels, branching probabilities and the Sudakov form factor - Parton-showers - Merging matrix elements with different multiplicities Next-to-leading order: - Infrared-safety: definition and classification of observables - How infra-red divergences arise in higher-order computations, and how to deal with them - Local subtraction methods. FKS and dipoles - (may be skipped if not enough time) Computation of one-loop diagrams - Matching NLO computations with parton-showers All topics will be complemented with hands-on tutorials on the students' computers.
Examination modalities	Exercises to be solved by the students.
Preliminary schedule	25-27 th of June Course enrolment deadline: December 27, 2025.