Università
degli Studi
di Padova

PHD OF NATIONAL INTEREST IN TECHNOLOGIES FOR FUNDAMENTAL RESEARCH IN PHYSICS AND ASTROPHYSICS

EDUCATIONAL OFFER – A.Y. 2024/25

Curriculum: ELECTROTECHNICS

- Collective effects in circular accelerators
- Physics, Technology and Applications of Linear Accelerators
- Physics of High Brightness Accelerators
- Applied Superconductivity: Quantum Phenomena and Quantum Systems
- Advanced scientific programming in Matlab
- Programmable System on Chip (SoC) for data acquisition and processing
- Coupled electrical-thermal-structural Finite Element Analyses
- Metal Additive Manufacturing
- Fundamentals of system engineering and project management for large scientific projects

Course unit English denomination	Collective effects in circular accelerators
Teacher in charge (if defined)	Mauro Migliorati
Teaching Hours	30
Number of ECTS credits allocated	3
Course period	March-June
Course delivery method	☐ In presence ☒ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (% minimum of presence) ☐ No
Course unit contents	Wakefield: Longitudinal and transverse wakefields, Definitions, Short and long range wakefields, Expansion in cylindrical symmetry, Coupling impedances, Example of RLC, Example of wakefield calculation and energy loss, Uniform boundary conditions, Resistive wall, Green's function method, Non-uniform boundary conditions, Example of using an electromagnetic code (CST), Broadband impedance models. Longitudinal instabilities in storage rings: Synchrotron oscillations, momentum compaction, Oscillations in energy, Finite and differential equation for a single particle and a macroparticle with wakefield, Longitudinal oscillations, Robinson instabilities in the fundamental mode, Fokker-Plank equation and stationary solution, Haissinski equation and potential pit distortion, Phase shift and incoherent frequency, Perturbative methods and coherent modes of oscillation, Instability by mode coupling, Macroparticle model, Instability produced by high Q resonators, Transverse instabilities: Vlasov's equation, Perturbative theory, Head-tail instability, Transverse mode coupling instability (TMCI) => From impedance but also from space charge, Beam-beam and electyron cloudi, Transverse instabilities of coupled modes, Instability of high-Q resonators, Resistive wall instability, Landau damping: Introduction and physical origin, Loss of Landau damping
Learning goals	The aim of the course is to provide the student with an overview of collective effects and instabilities in circular accelerator machines
Teaching methods	Lectures
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No

Prerequisites (not mandatory)	-
Examination methods (in applicable)	Assessment test and student presentation on one of the topics covered
Suggested readings	slides and handouts from the lecturer
Additional information	-

Course unit English denomination	Physics, Technology and Applications of Linear Accelerators
Teacher in charge (if defined)	D. Alesini
Teaching Hours	30
Number of ECTS credits allocated	3
Course period	July-October
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (% minimum of presence) ☐ No
Course unit contents	1) Introduction to the course and basics of LINAC acceleration structures 2) Normal and superconducting structures 3) Power coupling, scattering parameters, linac technology 4) High-power RF sources for particle accelerators 5) Longitudinal and transverse beam dynamics, bunching, capture sections, envelope equation 6) Magnet design: basic design principles and parameters: POISSON 7) Pumping system and linac vacuum basics 8) Timing and synchronisation systems 9) Diagnostic devices 10) ASTRA CODE for beam dynamics simulations: introduction and example of photoinjector design 11) Electronic thermionic cannons 12) Application of proton linacs for cancer therapy 13) Applications of electronic linacs: injectors, industrial applications, FEL, tomography
Learning goals	the main objective of the course is to provide an overview of physics (longitudinal and transverse dynamics), technology (radio-frequency cavities and systems, magnets, ultra-high vacuum systems) and the main applications of linear accelerators with particular reference to electron accelerators
Teaching methods	lectures
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No

Available for PhD students from other courses	☐ Yes ☐ No
Prerequisites (not mandatory)	-
Examination methods (in applicable)	in-presence or online. Illustration of topics presented during the course
Suggested readings	lecturer's slides and handouts
Additional information	-

Course unit English denomination	Physics of High Brightness Accelerators
Teacher in charge (if defined)	M. Ferrario
Teaching Hours	60
Number of ECTS credits allocated	6
Course period	March-June
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (% minimum of presence) ☐ No
Course unit contents	Course description - Light sources based on high-gain free-electron lasers or future high-energy linear colliders require the production, acceleration and transport to the point of interaction of low divergence, high charge density, short electron beams (high-brightness beams). Many effects generally contribute to the degradation of the final beam quality, including colour effects, wake fields, coherent radiation emission, accelerator misalignments, etc. In particular, space charge effects and mismatch with focusing and acceleration devices contribute to the degradation of the emittance of high charge-density beams, so the control of beam transport and acceleration is at the forefront of producing high quality beams. In these lectures, we introduce from basic principles the main concepts of beam focusing and transport in modern accelerators using the beam envelope equation as a convenient mathematical tool, suitable for any type of charged particle accelerator. Matching conditions that preserve beam quality are derived from the model for significant beam dynamics regimes. An extension of the model to the plasma accelerator case is also introduced. An understanding of the similarities and differences to conventional accelerators is emphasised. Course Details - The main topics covered during the lectures will include: - Overview of advanced accelerator techniques and their applications - The concepts of emittance, luminance and luminosity - Summary of relativistic dynamics - Phase space and Liouville's theorem - Beam thermodynamics - Longitudinal and transverse envelope equations - Space charge effects - Beam manipulation and emittance compensation - Wake fields and instability - Physics of free-electron lasers - Introduction to plasma accelerator physics - The EuPRAXIA project at LNF Dedicated seminars will be given by experts in specific fields of interest related to this course. A detailed visit to the current SPARC_LAB high luminosity facility at LNF will conclude the course.

Learning goals	Students will gain an understanding of new acceleration techniques, as well as advanced topics such as beam quality control, phase space dynamics, energy efficiency and collective instabilities.
Teaching methods	Lectures
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Electromagnetism, Special Relativity
Examination methods (in applicable)	in-depth presentation of a topic of your choice from those discussed during the course and follow-up questions
Suggested readings	slides and lecturer's handouts
Additional information	[1] J. B. Rosenzweig, “Fundamentals of beam physics”, Oxford University Press, New York, 2003 [2] M. Reiser, “Theory and Design of Charged Particle Beams” , Wiley, New York, 1994 [3] L. Serafini, J. B. Rosenzweig, Phys. Rev. E 55 (1997) 7565 [4] M. Ferrario et al., Phys. Rev. Let. 99, 234801 (2007) [5] Beam dynamics newsletter, n. 38 www-bd.fnal.gov/icfabd/Newsletter38.pdf [6] M. Ferrario et al., Phys. Rev. Let. 104, 054801 (2010) [7] T. Wangler, “Principles of RF linear accelerators”, Wiley, New York, 1998

Course unit English denomination	Applied Superconductivity: Quantum Phenomena and Quantum Systems
Teacher in charge (if defined)	- Awaiting resolution of the Academic Board of the relevant PhD (Applied Electronics, University of Roma Tre)
Teaching Hours	15
Number of ECTS credits allocated	currently undefined at the Doctoral Course to which it belongs
Course period	Second semester (March-October, to be defined)
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English. Italian if only Italian-speaking PhD students are present.
Mandatory attendance	☒ Yes (% minimum of presence) ☐ No
Course unit contents	*Fundamentals:* Introduction to superconductivity. Basics of microscopic theory. Superconducting materials. Thermodynamics of superconductors. Ginzburg-Landau theory. Phenomenology of the mixed state. Fluxons, fluxonic motion. Josephson effect. *Advanced topics:* Unconventional superconductivity. RF I superconductivity: superconductors for resonant cavities, for devices. RF Superconductivity II: presence of high dc magnetic fields, superconductors for experiments and infrastructure for fundamental physics (Haloscopes, FCC). Superconductivity in power applications (e.g. cables, magnets, FCL). Quantum metrology. Josephson devices. Qubit.
Learning goals	Superconductivity is a macroscopic quantum phenomenon with very different applications. The course aims at introducing the main roles of superconductivity in the fields of power applications, radiofrequency applications, metrology and quantum computing (from macroscopic to microscopic). The course presents first a short introduction to superconductivity and superconducting materials, and then a selection of the applications of superconductivity in the fields mentioned.
Teaching methods	Traditional teaching (slides, blackboard, possible problem assignment), with possible distance learning
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No

Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Electromagnetism (bachelor university level). Preferably basic training in solid-state physics.
Examination methods (in applicable)	Seminar at the end of the course.
Suggested readings	Provided during the course (slides, articles, book chapters).
Additional information	Delivered if taken at the PhD Course in Applied Electronics, University of Roma Tre. The course is adapted, where possible, to the PhD students' preparation and research projects. The dual mode is activated at the motivated request of the doctoral students.

Course unit English denomination	Advanced scientific programming in Matlab
Teacher in charge (if defined)	Paolo Bardella, Stefano Scialò
Teaching Hours	30
Number of ECTS credits allocated	6
Course period	January/February 2025
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☐ Yes (% minimum of presence) ☒ No
Course unit contents	1.5h: introduction to MATLAB, with particular attention on the improvements introduced in the latest versions 1.0h: source Control systems integrated in MATLAB (git) 1.5h: MATLAB internals: data structures, JIT, numerical libraries 3.0h: object oriented programming in MATLAB 3.0h: optimization of MATLAB code, use of the Code Profiler 3.0h: MEX files for the execution of C/C++ and Fortran code in MATLAB. MATLAB C code generator 3.0h parallel computing in MATLAB: introduction to parallel computing, commands parfor, spmd, advantages and limitations. 3.0h: GPUs in MATLAB: introduction to GPUs and gpuarray command 3.0h: optimization of I/O in MATLAB, control of hardware 3.0h: fundamentals of machine learning in MATLAB; Big data and tall arrays 1.0h: alternatives to MATLAB: python, Arrayfire, Gnu Scientific library, Octave, Scilab 4.0h: projects' presentation
Learning goals	The course aims to provide advanced skills in scientific programming, and to teach sound methodologies for the development of reliable, optimized and maintainable codes. During this course, many common methods used in Scientific Computing will be presented, with particular attention to the most recent programming techniques in MATLAB. At the end of the course, the student will have expanded his/her knowledge of MATLAB and will be able to choose the best approach for the solution of numerical problem he/she will face.
Teaching methods	Lectures
Course on transversal, interdisciplinary,	☒ Yes ☐ No

transdisciplinary skills	
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Basic knowledge of MATLAB language.
Examination methods (in applicable)	Presentation of group activity on the optimization of existing MATLAB code proposed by the students.
Suggested readings	Slides provided by the teachers, video recordings of the lessons, suggested texts on specific topics.
Additional information	-

Course unit English denomination	Programmable System on Chip (SoC) for data acquisition and processing
Teacher in charge (if defined)	Andrea Fabbri
Teaching Hours	20
Number of ECTS credits allocated	4
Course period	
Course delivery method	☐ In presence ☒ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☐ Yes (% minimum of presence) ☒ No
Course unit contents	The course will introduce the latest generation programmable devices (FPGA and ACAP) describing their characteristics and main modules (DDR management, integrated processors, DSP, AI engine…) and their interaction. Use cases will then be presented and a classroom project will be carried out aimed at learning the methodologies for using these complex systems in the field of data acquisition systems (DAQ) for physics and astrophysics equipment.
Learning goals	The main objective is to give the student a vision of the tools currently available on the market that can be used in the context of complex data acquisition systems. The student will be provided with the methodologies for the architectural design of such systems through the use of such platforms and hints on the relative programming methods.
Teaching methods	The course includes an introductory part in which the basic concepts related to the needed functionality of an acquisition systems. Moreover, the components integrated within a modern FPGA will be discussed and recalled. Two case studies will then be viewed in the classroom as an example of complex acquisition systems based on programmable devices.
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	-

Examination methods (in applicable)	Oral interview (By appointment)
Suggested readings	handouts provided by the teacher
Additional information	-

Course unit English denomination	Coupled electrical-thermal-structural Finite Element Analyses
Teacher in charge (if defined)	Giovanni Meneghetti, Mattia Manzolaro, Michele Ballan
Teaching Hours	10
Number of ECTS credits allocated	2
Course period	June 2025
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (% minimum of presence) ☐ No
Course unit contents	Course overview and introduction. General aspects of Finite Element analyses related to the structural, thermal and electrical fields. Structural analyses with plane and solid elements. Thermal analyses with plane and solid elements, implementing thermal conduction, thermal convection and thermal radiation. Coupled field thermal-structural analyses. Coupled field electrical-thermal analyses. Coupled field electrical-thermal-structural analyses. Presentation of a complex test case implementing all the aforementioned physical fields with a specific focus on complex geometry import.
Learning goals	The course is aimed at providing the fundamental know-how for the performance of Multiphysics Finite Element analyses related to the structural, thermal and electrical fields. ANSYS® will be the adopted engineering simulation software.
Teaching methods	Frontal lesson and tutorial
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	-
Examination methods (in applicable)	Report on a project developed by the PhD student

Suggested readings	- M. Manzolaro, G. Meneghetti, A. Andrighetto, Thermal–electric numerical simulation of a surface ion source for the production of radioactive ion beams, Nucl. Instrum. Methods Phys. Res., Sect. A 623 (2010) 1061–1069. - G. Meneghetti, M. Manzolaro, A. Andrighetto, Thermal–electric numerical simulation of a target for the production of radioactive ion beams, Finite Elem. Anal. Des. 47 (2011) 559–570. - M. Manzolaro, G. Meneghetti, INTRODUCTION TO THE THERMAL ANALYSIS WITH ANSYS® NUMERICAL CODE, edizioni LIBRERIA PROGETTO, 2014, Padova, ITALY. - G. Meneghetti, M. Manzolaro, M. Quaresimin, INTRODUCTION TO THE STRUCTURAL ANALYSIS WITH ANSYS® NUMERICAL CODE, edizioni LIBRERIA PROGETTO, 2014, Padova, ITALY.
Additional information	-

Course unit English denomination	METAL ADDITIVE MANUFACTURING
Teacher in charge (if defined)	Eng. Pietro Rebesan
Teaching Hours	16
Number of ECTS credits allocated	4
Course period	Second semester A.Y. 2024/25
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	Italian/English
Mandatory attendance	☒ Yes (75% minimum of presence) ☐ No
Course unit contents	The course provides students with the basic knowledge and skills for metal Additive Manufacturing (AM) including AM processes and their capabilities, raw materials production chain, designing AM parts according to design for additive manufacturing (DfAM) rules, AM software introduction, case study on materials production and characterization, main defects on additively manufactured metals components, simulation, and post-processing. Practical experience will be gained through individual projects and laboratory hands-on experience.
Learning goals	Understand the fundamental principles of metal additive manufacturing (AM). Identify AM processes and their capabilities. Analyze the raw materials production chain. Apply the principles of Design for Additive Manufacturing (DfAM). Use software for additive manufacturing. Evaluate case studies on AM materials production and characterization. Recognize common defects and post-processing phase in components produced via AM. Develop practical skills through individual or group projects.
Teaching methods	Lectures and exercises
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	no

Examination methods (in applicable)	Discussion/Report of a case study within the individual or group project
Suggested readings	Courses slides and papers recommended during the course
Additional information	

Course unit English denomination	Fundamentals of system engineering and project management for large scientific projects
Teacher in charge (if defined)	Marco Xompero / Runa Briguglio
Teaching Hours	12
Number of ECTS credits allocated	1,5
Course period	spring 2025
Course delivery method	x In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	x Yes (100% minimum of presence) ☐ No
Course unit contents	Today, scientific research projects are carried out by large international teams and involve a multi-disciplinary approach. In add, specific tools are requested: to organize the team-work, to meet the deadlines, to define a common language and comprehension across all the elements in the project. The system engineer and the project manager are key-figures in the organizational chart. System engineering is an approach for successful systems, focusing on the early analysis of the user needs, then proceeding with design synthesis and system validation considering the complete problem. Project management, in parallel, is related to the organizational aspects: the definition of who will be doing what and how, the creation and optimization of a project calendar, based on the activities prioritization and their conflicts, the identification and management of risks, and much more. The class is intended to provide PhD students with a basic package to understand the project's working mechanisms.
Learning goals	Project planning System management
Teaching methods	Slides and group work, analysis of use cases. The course is organized as a 2, 3 days workshop in Florence
Course on transversal, interdisciplinary,	x☐ Yes No

transdisciplinary skills	
Available for PhD students from other courses	☐ Yes x No
Prerequisites (not mandatory)	None
Examination methods (in applicable)	class work, organization of a custom project.
Suggested readings	None. References will be given during the classes
Additional information	https://sites.google.com/inaf.it/syseng-phdnazionale/home-page