Module handbook

for the joint study program

International Master of Advanced Methods in Particle Physics (IMAPP), Master of Science

offered by

Technische Universität Dortmund (TUDO),
Alma Mater Studiorum - Università di Bologna (UNIBO),
Université Clermont Auvergne (UCA)

Version: 02.03.2022

Table of Contents

Preface

Numbering scheme

The numbering scheme for modules is as follows:

IMAPP-[semester]-[course number],

where [semester] is the semester in which the module is taught and [course-number] is a continuous number.

Work load

According to the European Credit Transfer and Accumulation System (ECTS), the work load of one ECTS credit corresponds to 25 to 30 hours of work. Given the different lengths of the semesters in France, Germany and Italy as well as the different type and depth of the modules, the individual work load can vary. The work load quoted in the description of the modules below is calculated assuming 25 hours for consistency and represents the typical work load associated with the modules.

Mode of delivery

All courses are planned to be delivered face-to-face, but the mode of delivery can be changed in agreement with the students or external constraints. While distance learning is possible for most lectures and seminars, it is difficult to maintain for laboratory courses.

Examinations

Most modules are completed by an examination. If the type of examination is not fixed in the module description it has to be specified by the examiner no later than two weeks after the start of the course. Details about the examinations, e.g. the length and the announcement procedure, are detailed in Section 9 if the Examination Regulation.

Teaching methods

The teaching methods used depend on the type of course:

- “Lecture” for lecture-type courses and seminars given by invited speakers
- “Problem-based learning” for exercise sessions, e.g. in theoretical physics
- “Seminar” for presentations prepared by students
- “Directed discussion” for an in-class discussion of the presented material organized by the teacher
- “Laboratory method” for lab experiments conducted by the students and under supervision
- “Research” for the Master thesis and internships

Teachers can deviate from the teaching methods indicated given personal preferences.

Program learning outcomes

Students will acquire basic knowledge in the fundamentals of particle physics, in programming using modern computer languages, in instrumentation and detector physics as well as in statistics and machine learning. They will also obtain advanced knowledge in current problems in experimental and theoretical particle physics including state-of-the-art methodology and technology as well as the historical development. The students will learn to analyse and solve concrete and abstract problems. They will acquire skills important for scientific work and for scientifically oriented professional activities including the application of mathematical and technical methods to problems in particle physics, the critical discussion of scientific topics and the conduction of research projects in which they investigate a scientific problem. The students will be able to conduct independent research in particle physics or related fields on an international level. Furthermore, the students will obtain language and presentation skills (English, possibly French German and/or Italian) and practice geographical mobility.

Modules of the first semester

All modules of the first semester are offered by UCA. Compulsory modules sum up to 27 ECTS credits and students can choose from elective courses to obtain further credits.

Compulsory modules

No.	Module	ECTS	Graded
IMAPP-01-01	Introduction to quantum field theory and gauge theories	6	Yes
IMAPP-01-02	Introduction to particle physics and the experimental foundations of the Standard Model	9	Yes
IMAPP-01-03	Programming and data analysis	6	Yes
IMAPP-01-06	Statistics and artificial intelligence	6	Yes

Elective modules

No.	Module	ECTS	Graded
IMAPP-01-04	Guest lectures on various topics	3	Yes
IMAPP-01-05	UCA seminar on particle physics	3	No

Introduction to quantum field theory and gauge theories (IMAPP-01-01)				
Degree program: Advanced Methods in Particle Physics **Further degree programs:**				
Frequency: Winter semester	**Duration:** One semester	**Semester:** First semester	**Credits:** 6	**Work load:** 150 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	Lec	6	4
2	**Language:** English				
3	**Content** The course gives an introduction to the quantum field theory framework, starting from the classical field theory (Lagrangian, Hamiltonian and Nöther's theorem), introducing the free quantum field theory (from classical theory to quantum field theory, Fock spaces, free scalar field, free fermion, Dirac field), and covering concepts on interacting fields and Feynman diagrams (S matrix, Klein Gordon scalar field, Green functions, Wick theorem, Feynman diagrams, Dirac fields, generalities to derive the Feynman rules). Cross-sections and decay widths (normalizing the states; decay rates; cross-sections; application to 2-body final states) are discussed. The second part of the course gauge theories with QED as a living illustration, with an introduction to Local gauge invariance, abelian Higgs mechanism, Yang-Mills theory and renormalization. Finally QCD foundation will be introduced, namely the quark model, SU(2) and SU(3) groups, the color charge, QCD Lagrangian, Feynman rules, QCD colour factor, the running of the coupling constant alpha_s, QCD in different regimes: confinement, and asymptotic freedom, quark and gluon plasma, elastic scattering electron-proton.				
4	**Learning outcome** The students will acquire basic knowledge of quantum field theory, on how quantum mechanics and special relativity are combined to produce realistic theories of particle creation and annihilation. They will obtain skills in calculation techniques to at least tree-level Feynman diagrams for quantum electrodynamics; acquisition of foundation for more advanced studies in Standard Model theory.				
5	**Teaching methods** Lecture (80%) and problem-based teaching (20%)				
6	**Examination** Graded module				
7	**Coursework and examination requirements** Coursework: To be defined by the lecturer. Examination: Oral or written examination.				
8	**Prerequisites** Quantum mechanics, mathematics				

9	**Recommended literature** M. Peskin, D. Schroeder, *Quantum Field Theory*, CRC Press, 1995. Further scientific literature and specific publications are distributed in the class.	
10	**Module type** Compulsory module	
11	**Responsible** Prof. Dr. Jean Orloff	**Organization** University of Clermont Auvergne, Department of Physics

Introduction to particle physics and the experimental foundations of the Standard Model (IMAPP-01-02)				
Degree program: Advanced Methods in Particle Physics **Further degree programs:**				
Frequency: Winter semester	**Duration:** One semester	**Semester:** First semester	**Credits:** 9	**Work load:** 225 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	Lec	9	6
2	**Language:** English				
3	**Content** The course covers basic concepts of the Standard Model of Particle Physics. The introduction part of the course introduces the Dirac equation (solutions and interpretation), particle decay width and cross-sections, interaction by particle exchange, matrix element, example of Feynman rules for QED, interaction strength (EM, strong and weak interactions), higher order effects (Lamb's shift, anomalous magnetic moment, and a brief introduction to renormalization in QED). An overview about continuous and discrete symmetries in Physics is given with particle physics and solid state physics illustrations. Finally, the course covers the Standard Model of Particle Physics. Electroweak unification and the spontaneous electroweak symmetry breaking (EWSB) by the Brout-Englert-Higgs mechanism are discussed. Following EWSB, the mass mixing matrices are introduced and further discussed in subsequent lectures featuring lepton and quark flavour phenomenology and discussing recent experimental results.				
4	**Learning outcome** The students will acquire basic knowledge about the Standard Model of particle physics and of the experimental processes, methods and historical measurements. They will be able to judge the consistency of physical models and to apply mathematical methods to the problems at hand.				
5	**Teaching methods** Lecture (80%) and problem-based teaching (20%)				
6	**Examination** Graded module				
7	**Coursework and examination requirements** Coursework: To be defined by the lecturer. Examination: Oral or written examination.				
8	**Prerequisites** None				
9	**Recommended literature** M. Thomson, Modern Particle Physics, Cambridge University Press, 2013,				

	F. Halzen, A. Martin, Quarks and Leptons, Wiley, 1984, scientific literature and specific publications are distributed during the class	
10	**Module type** Compulsory module	
11	**Responsible** Prof. Dr. Stephane Monteil	**Organization** University of Clermont Auvergne, Department of Physics

Programming and data analysis (IMAPP-01-03)				
Degree program: Advanced Methods in Particle Physics **Further degree programs:**				
Frequency: Winter semester	**Duration:** One semester	**Semester:** First semester	**Credits:** 6	**Work load:** 150 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	Lec	6	4
2	**Language:** English				
3	**Content** The programming part of the lecture covers a practical introduction (object, collections, functions, loops and few pythonics syntax, basic file manipulation), Numpy introduction (numpy arrays vs python list, vectorization, (fancy) indexing, broadcasting), Data analysis python ecosystem (overview, data representation: matplotlib, import/manipulate data: pandas, mathematics, physics and engineering: scipy), and basics of image processing (loading/plotting, colors, grey scale, image filters: kernel, blocks, sliding windows). The second part of the lecture is about manipulation of data, so-called data mining and includes data preprocessing (data visualization, data cleaning, data space transformation), clustering (hierarchical clustering, partitional clustering), association rules, feature reduction (feature extraction, feature reduction) and hands-on sessions.				
4	**Learning outcome** The students will acquire extended knowledge about the python language and computing tools to deal with and manipulate mass data. The programming course brings to the students the pre-requisites for advanced applications in the machine learning module. The student will be able to write programs to solve simple problems using the methodologies treated in the lectures.				
5	**Examination** Graded module				
6	**Teaching methods** Lecture (50%) and problem-based teaching (50%)				
7	**Coursework and examination requirements** Coursework: To be defined by the lecturer. Examination: Oral or written examination.				
8	**Prerequisites** None				
9	**Recommended literature** Scientific literature and specific publications are distributed during the class				
10	**Module type** Compulsory module				

11	**Responsible** Dr. Romain Madar	**Organization** University of Clermont Auvergne, Department of Physics

Statistics and artificial intelligence (IMAPP-01-06)				
Degree program: Advanced Methods in Particle Physics **Further degree programs:**				
Frequency: Winter semester	**Duration:** One semester	**Semester:** First semester	**Credits:** 6	**Work load:** 150 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	Lec	6	4
2	**Language:** English				
3	**Content** This course introduces basics of statistics and modern methodologies and algorithms to solve complex problems in data analysis with Artificial intelligence and machine learning (ML). The first part of the lecture covers samples (description and definition of basic quantities: size, dimension, iid, empirical quantities: sample mean, sample variance, quantiles, propagation of uncertainties, binned samples: definition, law of probability), statistical models (definition, ingredients of statistical models: observables, parameters of interest, nuisance parameters, dependent and independent variables, likelihood function and extended likelihood function, composite statistical models, introduction to the treatment of nuisance parameters), inference (introduction to the inference problem, introduction to the frequentist and the Bayesian approaches), and parameter estimation (definition of estimator, properties of estimators: consistency, bias, efficiency, methods for estimating parameters: maximum likelihood, least squares, Bayesian inference). The second part covers basic concepts of machine learning (introduction to ML, deep learning and representation learning, training and testing, cross validation, bias-variance decomposition, curse of dimensionality), regression with linear models (simple exemple: polynomial curve fitting, linear basis function models, regularization, likelihood and regression), and classification (linear models for classification, perceptron algorithm, linear discriminant analysis, logistic regression, Artificial Neural Networks, popular NN algorithms).				
4	**Learning outcome** The students will acquire extended knowledge about statistics, from the mathematical foundations to their applications in particle physics and beyond. A second lecture provides the students with skills about machine learning algorithms.				
5	**Examination** Graded module				
6	**Teaching methods** Lecture (70%) and problem-based teaching (30%)				
7	**Coursework and examination requirements** Coursework: To be defined by the lecturer. Examination: Oral or written examination.				

8	**Prerequisites** Programming and data analysis delivered IMAPP-01-03 (in parallel)	
9	**Recommended literature** Scientific literature and specific publications are distributed during the class	
10	**Module type** Compulsory module	
11	**Responsible** Prof. Dr. Julien Donini	**Organization** University of Clermont Auvergne, Department of Physics

Guest lectures on various topics (IMAPP-01-04)				
Degree program: Advanced Methods in Particle Physics **Further degree programs:**				
Frequency: Winter semester	**Duration:** One semester	**Semester:** First semester	**Credits:** 3	**Work load:** 75 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	Lec	3	2
2	**Language:** English				
3	**Content** The topics of the guest lectures come from the field of particle physics or related subjects, e.g. cosmology or mathematics. The topics and content of the lecture will be announced prior to the semester.				
4	**Learning outcome** The students will acquire insight knowledge about basic knowledge or current topics in particle physics or related fields.				
5	**Teaching methods** Lecture (100%)				
6	**Examination** Graded module				
7	**Coursework and examination requirements** Coursework: Active participation Examination: Oral examination				
8	**Prerequisites** Basic knowledge of particle physics				
9	**Recommended literature** Scientific literature and specific publications are distributed during the class				
10	**Module type** Elective module				
11	**Responsible** Prof. Dr. Stephane Monteil, Guest lecturer		**Organization** University of Clermont Auvergne, Department of Physics		

UCA seminar on particle physics (IMAPP-01-05)				
Degree program: Advanced Methods in Particle Physics **Further degree programs:**				
Frequency: Winter semester	**Duration:** One semester	**Semester:** First semester	**Credits:** 3	**Work load:** 75 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	Sem	3	2
2	**Language:** English				
3	**Content** This course covers current topics on experimental and theoretical particle physics.				
4	**Learning outcome** The students will gain knowledge in current topics of experimental and theoretical physics that goes beyond the material covered in the introductory modules. Students will improve their skills critical thinking and discussions. Students will also acquire the skill of finding and studying related literature and other learning material independently in preparation for the seminar.				
5	**Teaching methods** Lecture (100%)				
6	**Examination** Ungraded module				
7	**Coursework and examination requirements** Coursework: None Examination: None				
8	**Prerequisites** Basic knowledge of particle physics				
9	**Recommended literature** None				
10	**Module type** Elective module				
11	**Responsible** Dr. Andreas Goudelis		**Organization** CNRS, University of Clermont Auvergne, Department of Physics		

Modules of the second semester

All modules of the second semester are offered by TUDO. Compulsory modules sum up to 24 ECTS credits and students can choose from elective courses to obtain further credits. In the following, courses from the regular Master program in Physics at TUDO are indicated by an identifier PHYxyz.

Compulsory modules

No.	Module	ECTS	Graded
IMAPP-02-01	Model building in particle physics	6	Yes
IMAPP-02-02	Practical aspects of particle physics measurements	6	Yes
IMAPP-02-03	Detector systems in particle and medical physics	9	Yes
IMAPP-02-04	Spring/Summer school	3	No

Elective modules

No.	Module	ECTS	Graded
IMAPP-02-05	Electronics lab course	6	Yes
IMAPP-02-06	Modern particle physics	6	Yes
IMAPP-02-07	Astroparticle physics	3	Yes
IMAPP-02-08	Guest lecture on instrumentation	3 or 6	Yes
IMAPP-02-09	TUDO seminar on particle physics	3	No

Model building in particle physics (IMAPP-02-01)				
Degree program: Advanced Methods in Particle Physics **Further degree programs: Master Physics (TU Dortmund University)**				
Frequency: Summer semester	**Duration:** One semester	**Semester:** Second semester	**Credits:** 6	**Work load:** 150 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture “SM physics and BSM directions”	Lec	3	2
	2	Seminar „Physics beyond the SM“ (**PHY736**)	Sem	3	2
2	**Language:** English				
3	**Content** Various models in particle physics and their theoretical background including the flavor problem and observables, rare decays, effective theories, dark matter, the Higgs sector, quantum gravity and asymptotic safety, model building and phenomenology as well as recent experimental results.				
4	**Learning outcome** The students will acquire knowledge in different models uses in particle physics and the phenomenology connected to those. They will critically judge the validity of the models based on measurements and experimental tests. The students will improve their presentational skills and learn how to discuss critically.				
5	**Teaching methods** No. 1: either lecture (100%) or seminar (50%) and directed discussion (50%). No. 2: seminar (50%) and directed discussion (50%)				
6	**Examination** Graded module				
7	**Coursework and examination requirements** Coursework: A presentation in the seminar and an active participation in the courses. Examination: Oral or written examination.				
8	**Prerequisites:** Basic knowledge of particle physics and quantum field theory				
9	**Recommended literature** M. Fukugita,T. Yanagida, *Physics of Neutrinos*, Springer, 2003				
10	**Module type** Compulsory module				
11	**Responsible** Prof. Dr. Gudrun Hiller, Prof. Dr. Heinrich Päs	**Organization** TU Dortmund University, Department of Physics			

Practical aspects of particle physics measurements (IMAPP-02-02)				
Degree program: Advanced Methods in Particle Physics **Further degree programs: Master Physics (TU Dortmund University)**				
Frequency: Summer semester	**Duration:** One semester	**Semester:** Second semester	**Credits:** 6	**Work load:** 150 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture (**PHY822**)	Lec	3	2
	2	Excercises (**PHY822**)	Ex	3	2
2	**Language:** English				
3	**Content** Basic experimental methods in accelerator-based particle physics; interpretation of the data; methods of conducting data analysis including data preparation, physics objects, statistical modelling and the treatment of systematic uncertainties; phenomenology of different processes and recent experimental results including searches for new phenomena, precision measurements as well as an overview of current and future experiments.				
4	**Learning outcome** The students will obtain knowledge on the basics of experimental particle physics and the methods used. They will acquire advanced knowledge about the statistical analysis of collider data and recent experimental results. The students will apply their knowledge on concrete problems encountered in such analyses. They will be able to understand all steps necessary for interpreting large data sets from collider experiments.				
5	**Teaching methods** Lecture (80%) and problem-based teaching (20%)				
6	**Examination** Graded module				
7	**Coursework and examination requirements** Coursework: Active participation in the exercise sessions. Examination: Oral or written examination.				
8	**Prerequisites** Basic knowledge of particle physics				
9	**Recommended literature** Scientific literature and specific publications are distributed during the class				
10	**Module type** Compulsory module				

11	**Responsible** Prof. Dr. Johannes Albrecht	**Organization** TU Dortmund University, Department of Physics

Detector systems in particle and medical physics (IMAPP-02-03)				
Degree program: Advanced Methods in Particle Physics				
Frequency: Summer semester	**Duration:** One semester	**Semester:** Second semester	**Credits:** 9	**Work load:** 225 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Advanced Laboratory course: Particle physics (**PHY843**)	Lab	6	4
	2	Seminar on detector systems in particle and medical physics (**PHY826**)	Sem	3	2
2	**Language:** English				
3	**Content** No. 1: experimental techniques in particle physics including detector physics (semiconductor and scintillating fiber detectors), data analysis (CP violation and top-quark physics, reconstruction of particles) and advanced statistical methods (machine learning). No. 2: Different types of detectors used in particle and/or medical physics, e.g. semiconductor and scintillation detectors, X-ray detection systems. Detector systems and components composed of different types, e.g. calorimeters, modern particle physics experiments, PET, CT, etc.				
4	**Learning outcome** The students will obtain basic knowledge about particle and medical physics detectors, the technology used and the further processing of such data. They will understand how complex detector systems work and will apply their knowledge to laboratory experiments. The students will understand the relationship between the primary interactions of the particles to be detected with the entire material traversed and the different design methodologies. This leads to an understanding of the respective advantages and disadvantages of the construction types for various detector components. Furthermore, the student will acquire skills for critical reading of the literature and presentational skills.				
5	**Teaching methods** No. 1: Laboratory method (50%). No. 2: seminar (50%) and directed discussion (50%)				
6	**Examination** Graded module				
7	**Coursework and examination requirements** Coursework: Completion of laboratory experiments and a presentation in the seminar Examination: Oral examination				
8	**Prerequisites** Basic knowledge of particle physics				

9	**Recommended literature** Scientific literature and specific publications are distributed during the class	
10	**Module type** Compulsory module	
11	**Responsible** Prof. Dr. Kevin Kröninger	**Organization** TU Dortmund University, Department of Physics

Spring/Summer school (IMAPP-02-04)				
Degree program: Advanced Methods in Particle Physics **Further degree programs: Master Physics (TU Dortmund University)**				
Frequency: Summer semester	**Duration:** One semester	**Semester:** Second semester	**Credits:** 3	**Work load:** 75 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Spring/summer school	Lec	3	block course
2	**Language:** English				
3	**Content** Varying topics from the field of particle physics and related subjects including recent results in flavor physics, top-quark and Higgs physics, neutrino physics and future experiments. Short presentation of the participants' research experiences.				
4	**Learning outcome** The students will obtain an overview on the most important and updated experimental results in the field of particle physics. They will also improve their presentational and critical discussion skills.				
5	**Teaching methods** Lecture (70%), seminar (20%) and directed discussion (10%)				
6	**Examination** Ungraded module				
7	**Coursework and examination requirements** Coursework: A presentation during the school. Examination: None.				
8	**Prerequisites** Basic knowledge of particle physics				
9	**Recommended literature** None				
10	**Module type** Compulsory module				
11	**Responsible** Prof. Dr. Kevin Kröninger	**Organization** TU Dortmund University, Department of Physics			

Electronics lab course (IMAPP-02-05)				
Degree program: Advanced Methods in Particle Physics **Further degree programs: Master Physics (TU Dortmund University), Master Medical Physics (TU Dortmund University)**				
Frequency: Summer semester	**Duration:** One semester	**Semester:** Second semester	**Credits:** 6	**Work load:** 150 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Advanced Laboratory course: Electronics (**PHY845**)	Lab	6	4
2	**Language:** English				
3	**Content** Basic concepts of analog and digital electronics as well as their applications. The course comprises five experiments in which the functions and characteristics of diodes, transistors and amplifiers are studied as well the basics of digital networks.				
4	**Learning outcome** The students will acquire knowledge about the basic concepts of analog and digital electronics. They will understand the properties and characteristics of individual components and build simple circuits and networks. The student will gain expertise in working with real circuits and standard measurement setups. The laboratory experience will allow the student to develop social skills working in teams.				
5	**Teaching methods** Laboratory method (100%)				
6	**Examination** Graded module				
7	**Coursework and examination requirements** Coursework: Completion of laboratory experiments Examination: Oral examination				
8	**Prerequisites** None				
9	**Recommended literature** Scientific literature and specific publications are distributed during the class				
10	**Module type** Elective module				
11	**Responsible** Dr. Jens Weingarten	**Organization** TU Dortmund University, Department of Physics			

Modern particle physics (IMAPP-02-06)				
Degree program: Advanced Methods in Particle Physics **Further degree programs: Master Physics (TU Dortmund University)**				
Frequency: Summer semester	**Duration:** One semester	**Semester:** Second semester	**Credits:** 6	**Work load:** 150 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar False Discoveries in Particle Physics (**PHY827**)	Sem	3	2
	2	An additional seminar on modern particle physics, e.g. Machine Learning for Physicists (**PHY626**) or a Reading Course on Particle Physics (**PHY7215**)	Sem	3	2
2	**Language:** English				
3	**Content** No. 1: Discussion of results and discoveries in the field of particle physics that have been proven wrong. Connection to current research and modern methods of research. No. 2: Modern tools used in particle physics, e.g. machine learning, or in-depth studies of recent discoveries and measurements using modern methods.				
4	**Learning outcome** The students deepen their knowledge in the field of the particle physics by self-study. They also train skills in the area of scientific research and presentation techniques. In addition to these classic skills, the seminar helps students become aware of the rules of good scientific practice and reflect on potential problems. They will acquire advanced knowledge on modern methods used in particle physics.				
5	**Teaching methods** Both: seminar (50%) and directed discussion (50%)				
6	**Examination** Graded module				
7	**Coursework and examination requirements** Coursework: Active participation in the two seminars Examination: A presentation in at least one of the seminars				
8	**Prerequisites** Basic knowledge of particle physics				
9	**Recommended literature** Scientific literature and specific publications are distributed during the class				
10	**Module type** Elective module				

11	**Responsible** Prof. Dr. Johannes Albrecht, Prof. Dr. Kevin Kröninger	**Organization** TU Dortmund University, Department of Physics

Astroparticle physics (IMAPP-02-07)				
Degree program: Advanced Methods in Particle Physics **Further degree programs: Master Physics (TU Dortmund University)**				
Frequency: Summer semester	**Duration:** One semester	**Semester:** Second semester	**Credits:** 3	**Work load:** 75 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture Astroparticle Physics (**PHY823.2**)	Lec	3	2
2	**Language:** English				
3	**Content** Early Universe: Big bang, inflation and thermal evolution of the cosmos. Freeze-out and heavy relics. Cosmic neutrino background. Propagation of energetic particles: Absorption processes, extragalactic radiation fields, plasmas in interstellar and intergalactic space, particle interactions. Dark matter: models beyond the standard model of particle physics, indicators, halo formation and evolution, power spectrum of density fluctuations, direct and indirect search for dark matter with ground- and space-based experiments. AGN - models: leptonic and hadronic models for blazars. Inverse Compton scattering, internal and external radiation fields, photohadronic and pp models, implications for gamma and neutrino observations. Gravitational waves: experimental detection methods and multi-messenger astronomy.				
4	**Learning outcome** Students learn content from the most current research questions in astroparticle physics and cosmology with a special focus on the processes associated with strong gravity and the early universe. Advanced phenomenological computational techniques and scientific critical reading and classification of recent experimental and theoretical publications are also learned.				
5	**Teaching methods** No. 1: lecture (100%). No. 2: problem-based learning (100%)				
6	**Examination** Graded module				
7	**Coursework and examination requirements** Coursework: Successful participation in the exercises Examination: Written/oral examination				
8	**Prerequisites** Basic knowledge of particle physics				
9	**Recommended literature** R. Schlickeiser, *Cosmic Ray Astrophysics*, Springer, 2002. S. Weinberg, *Gravitation and Cosmology: Principles And Applications Of The General Theory Of Relativity*, Steven Weinberg, Wiley India, 2017.				

	T. L. Chow, *Gravity, Black Holes, and the Very Early Universe. An Introduction to General Relativity and Cosmology*, Springer, 2007. A. Pimenta, M. DeAngelis, *Introduction to Particle and Astroparticle Physics: Multimessenger Astronomy and its Particle Physics Foundations*, Springer, 2018, G. Sigl, *Astroparticle Physics: Theory and Phenomenology*, Springer, 2017, E. Kolb, M. Turner, *The Early Universe*, CRC Press, 2018.	
10	**Module type** Elective module	
11	**Responsible** Prof. Dr. Dr. Wolfgang Rhode	**Organization** TU Dortmund University, Department of Physics

Guest lecture on instrumentation (IMAPP-02-08)				
Degree program: Advanced Methods in Particle Physics **Further degree programs: Master Physics (TU Dortmund University), Master Medical Physics (TU Dortmund University)**				
Frequency: Summer semester	**Duration:** One semester	**Semester:** Second semester	**Credits:** 3 or 6	**Work load:** 75 h or 150 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Module Practical aspects of instrumentation (PHY7233)	Lec	3	2
	2	Optional: Module Practical aspects of instrumentation (PHY7233)	Sem	3	2
2	**Language:** English				
3	**Content** No. 1: The lecture covers basic principles of instrumentation, electronics and sensor technology. The characterization of instruments, aspects of data acquisition as well as measurement procedures is discussed. Furthermore, applications of instrumentation in specific fields of research, e.g. particle physics, condensed matter physics or medical physics, are presented. Current developments in instrumentation are briefly reported on. No. 2: The seminar focuses on the historical development of instrumentation in specific fields of research. Concrete examples for modern instrumentation systems, e.g. in spectroscopy, particle physics or medical imaging, are discussed.				
4	**Learning outcome** The students acquire basic knowledge of modern instrumentation. They are able to name and explain different sensor and detection principles, and understand the composition of common instrumentation systems. Furthermore, the students acquire skills for the critical reading of the literature and improve their presentation techniques.				
5	**Teaching methods** No. 1: lecture (100%). No. 2: seminar (50%) and directed discussion (50%)				
6	**Examination** Graded module				
7	**Coursework and examination requirements** Coursework: Active participation Examination: Oral examination				
8	**Prerequisites** Basic knowledge of particle physics				
9	**Recommended literature** H. Kolanoski, N. Wermes, *Particle Detectors: Fundamentals and Applications*, Oxford University Press, 2020				

	G. Knoll, *Radiation Detection and Measurement*, Wiley, 2010	
10	**Module type** Elective module	
11	**Responsible** Prof. Dr. Kevin Kröninger, visiting guest lecturer	**Organization** TU Dortmund University, Department of Physics

TUDO seminar on particle physics (IMAPP-02-09)				
Degree program: Advanced Methods in Particle Physics **Further degree programs: Master Physics (TU Dortmund University)**				
Frequency: Summer semester	**Duration:** One semester	**Semester:** Second semester	**Credits:** 3	**Work load:** 75 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	Sem	3	2
2	**Language:** English				
3	**Content** This course covers current topics on experimental and theoretical particle physics.				
4	**Learning outcome** The students will gain knowledge in current topics of experimental and theoretical physics that goes beyond the material covered in the introductory modules. Students will improve their skills critical thinking and discussions. Students will also acquire the skill of finding and studying related literature and other learning material independently in preparation for the seminar.				
5	**Teaching methods** Lecture (80%) and directed discussion (20%)				
6	**Examination** Ungraded module				
7	**Coursework and examination requirements** Coursework: None Examination: None				
8	**Prerequisites** Basic knowledge of particle physics				
9	**Recommended literature** Will be specified by the speaker				
10	**Module type** Elective module				
11	**Responsible** Prof. Dr. Kevin Kröninger		**Organization** TU Dortmund University, Department of Physics		

Modules of the third semester

All modules of the third semester are offered by UNIBO. Compulsory modules sum up to 27 ECTS. No elective courses are foreseen. The module "Research lab" is seen as an introduction into the field of research and the preparation for the research conducted in the fourth semester.

Compulsory modules

No.	Module	ECTS	Graded
IMAPP-03-01	Advanced standard model	6	Yes
IMAPP-03-02	Flavour physics in theory and experiment	6	Yes
IMAPP-03-03	Computer science for High energy physics	12	Yes
IMAPP-03-04	Orientation course for scientific research	6	Yes

Advanced Standard Model (IMAPP-03-01)				
Degree program: Advanced Methods in Particle Physics **Further degree programs:**				
Frequency: Winter semester	**Duration:** One semester	**Semester:** Third semester	**Credits:** 6	**Work load:** 150 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	Lec	6	4
2	**Language:** English				
3	**Content** The course provides advanced knowledge of the theory of the Standard Model of elementary particle with open questions from a theoretical and phenomenological perspective. The course is divided into three parts. The first part places a focus on neutrino physics (Neutrinos in the Standard Model. Neutrino oscillations in vacuum and in matter. Current status and open questions for the future. Nature and masses of neutrinos: Majorana and Dirac particles. Origin of neutrino masses beyond the Standard Model. The baryon asymmetry and leptogenesis. The problem of flavour in the lepton sector. Neutrinos in the Universe. Brief overview of dark matter). The second part is on precision Standard Model physics (Lagrangian of the SM. Custodial Symmetry and the rho parameter. Linear and non-linear EW symmetry breaking. EW chiral Lagrangian. Unitarity and perturbativity of the SM. Higgs mass bounds: unitarity, triviality and stability. EW precision-observables (EWPO) and renormalisation schemes. Higgs phenomenology: decays and production. Top-quark phenomenology: decays and single and pair production). The third part is dedicated to effective field theories (Introduction. Motivation and basic concepts. Simple examples. Machinery and Tools: matching, power counting, equations of motion, running, toy models. Applications: Fermi Theory, Euler-Heinsenberg, FCNC, NRQED. The Standard Model as an Effective Field Theory: Linear and non-linear extensions. Phenomenology and constraints from precision experiments. SMEFT at the LHC and future colliders).				
4	**Learning outcome** The student will get acquainted with the properties and features of our current description of the fundamental particles and their interactions. Motivated by its theoretical limitations as well as by the current experimental observations, the students will then be exposed to the most common avenues towards extending the Standard Model and searching for new physics in high-energy experiments.				
5	**Teaching methods** Lecture (100%)				
6	**Examination** Graded module				

7	**Coursework and examination requirements** Coursework: To be defined by the lecturer. Examination: Written examination.	
8	**Prerequisites** Quantum field theory	
9	**Recommended literature** M. Schwartz, *Quantum Field Theory and the Standard Model,* Cambridge University Press, 2014 C. Giunti, C. W. Kim, *Fundamentals of Neutrino Physics and Astrophysics*, Oxford University Press, USA, 2007	
10	**Module type** Compulsory module	
11	**Responsible** Prof. Dr. Fabio Maltoni	**Organization** University of Bologna, Department of Physics

Flavour physics in theory and experiment (IMAPP-03-02)				
Degree program: Advanced Methods in Particle Physics **Further degree programs:**				
Frequency: Winter semester	**Duration:** One semester	**Semester:** Third semester	**Credits:** 6	**Work load:** 150 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	Lec	6	4
2	**Language:** English				
3	**Content** The course covers aspects of flavor physics in the hadronic and the leptonic sector. The first part of the lecture focuses on the weak hadronic Interaction and CP violation: weak charged current interaction and its classification, the Fermi constant, Cabibbo mixing, the Glashow-Iliopoulos-Maiani mechanism, quark mixing and the Cabibbo-Kobayashi-Maskawa (CKM) matrix, weak neutral currents, quantum mechanical oscillations in the K, D, and B meson systems and experimental results, CP violation in the K, D, and B meson decays and experimental results, the unitarity triangle of the CKM matrix and the current experimental knowledge. Rare K, D, and B decays and experimental results. The indirect search for new physics with flavour physics experiments. The second part focuses on flavour physics in the leptonic sector: charged and neutral leptons in the Standard Model, physics of massive neutrinos, the mechanism of neutrino mass generation, neutrino cross sections, experimental searches in the framework of seesaw mechanisms (colliders, beam dumps), neutrinoless double beta decay, flavour mixing and CP violation in the neutral sector, short/medium/long baselines (accelerators and reactors), connection with cosmology, leptogenesis, the dark sector, flavour violation in the charged sector, electron and muon magnetic dipole moments.				
4	**Learning outcome** At the end of the course the student will become familiar with the basic concepts of heavy flavor and neutrino physics. He/she will get acquainted with the rich CKM and PMNS phenomenology, from CP violation in the hadronic and leptonic sectors up to search for New Physics through the measurements of rare decays and the quest for Majorana fermions at low energy and at colliders. The student will also be able to conceive an experimental apparatus useful for these searches and distinguish between the main experimental techniques used to reach this goal				
5	**Teaching methods** Lecture (100%)				
6	**Examination** Graded module				
7	**Coursework and examination requirements** Coursework: To be defined by the lecturer.				

	Examination: Oral or written examination.	
8	**Prerequisites** Quantum field theory	
9	**Recommended literature** M. Thomson, Modern Particle Physics, Cambridge University Press, 2013 I. I. Bigi, A. I. Sanda, CP violation, Cambridge University Press, 2010	
10	**Module type** Compulsory module	
11	**Responsible** Prof. Dr. Angelo Carbone	**Organization** University of Bologna, Department of Physics

Computer science for High energy physics (IMAPP-03-03)				
Degree program: Advanced Methods in Particle Physics **Further degree programs:**				
Frequency: Winter semester	**Duration:** One semester	**Semester:** Third semester	**Credits:** 12	**Work load:** 300 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	Lec	12	8
2	**Language:** English				
3	**Content** The course is divided in three parts. The first part covers Statistical data analysis for high energy physics including Concept of probability, Conditional probability. Statistical independence. Bayes' theorem. Random variables and probability density functions. Multivariate distributions. Marginal and conditional densities. Functions of random variables. Distribution moments. Examples of probability distributions. Central Limit Theorem. Statistical inference. Fisher information. Test statistics and sufficient test statistics. Monte Carlo methods. Variance reduction. Random number generators. Sampling a generic distribution. Generalities on statistical estimators. Test statistics and estimators. Estimators for the expectation value, variance and correlation. Variance of the estimators. The maximum likelihood method. Score and Fisher information. Multi-parametric estimator uncertainties with correlations. Extended Maximum Likelihood. Bayesian estimators, Jeffrey's priors. Least squares method. Hypothesis testing. Simple hypotheses. Efficiency and power of the test. Neyman-Pearson lemma. Linear test, Fisher's discriminant. Multivariate methods. P-values. Look-Elsewhere Effect. Chi-square method for hypothesis testing. Exact methods for the construction of confidence intervals. Gauss and Poisson case. Unified approach. Bayesian method. CLs method. Systematic errors and nuisance parameters in the calculation of confidence intervals. Frequentist and Bayesian methods. Asymptotic properties. Lab: Elements of C++ and ROOT. RooFit Workspace, Factory, composite models, multi-dimensional models. Use of RooStats to compute confidence intervals, Profile Likelihood, Feldman-Cousins, Bayesian intervals, w/ and w/o nuisance parameters. Use of TMVA as classifier, description of TMVAGui. The second part is an Introduction to data processing infrastructures for scientific applications including basic concepts of Infrastructures for processing and for running scientific applications. In particular it will focus on the Infrastructure-as-a-Service Cloud paradigm. The course will start with an introduction to Big Data and how they are related to scientific applications. It will continue with a description of the building blocks of modern Data Centers and how they are abstracted by the Cloud computing models. A real-life computational challenge will be given and students will create (during the course) a Cloud-based computing model to solve this challenge. Access to a limited set of Cloud resources and services will be granted to students in order to complete the exercises. Containers and in particular Docker Containers will be introduced as for the concept of High Performance Computing (HPC). Notions					

	about the emerging “Fog” and “Edge” computing paradigms and how they are linked to Cloud infrastructures will conclude the course. The third part is on Avdanced C++ programming for computer science an cover the use of modern C++ to efficiently exploit the memory hierarchy and the heterogeneous nature of current computer architectures. Further application of C++ programming techniques including subjects such as file access, abstract data structures, class inheritance, and other advanced techniques. The following C++ programming topics are covered: classes, objects, function and operator overloading, inheritance and dynamic polymorphism, templates, exception handling, standard template library, data structures, complex input/output standard and file handling techniques, program documentation, bit manipulation and other advanced C++ techniques.	
4	**Learning outcome** At the end of the course the student will acquire a knowledge in advanced statistics, programming languages and tools for data processing. Furthermore, the student will learn the fundamental aspect of a data centre dedicated to scientific computation.	
5	**Teaching methods** Lecture (80%) and problem-based teaching (20%)	
6	**Examination** Graded module	
7	**Coursework and examination requirements** Coursework: To be defined by the lecturer. Examination: Oral examination including the preparation of a small project.	
8	**Prerequisites** None	
9	**Recommended literature** F. James, *Statistical Methods in Experimental Physics*, World Scientific, 2007 G. Cowan, *Statistical Data Analysis*, Oxford Univ. Press, 1998 O. Behnke *et al.*, *Data Analysis in High Energy Physics: A Practical Guide to Statistical Methods*, Wiley, 2013 A. G. Frodesen, O. Skjeggestad, H. Toft, *Probability and Statistics in Particle Physics*, Universitetforlaget, 1979 G. D'Agostini, *Bayesian reasoning in data analysis - A critical introduction*, World Scientific Publishing, 2003	
10	**Module type** Compulsory module	
11	**Responsible** Dr. Francesco Giacomini	**Organization** University of Bologna, Department of Physics

Orientation course for scientific research (IMAPP-03-04)				
Degree program: Advanced Methods in Particle Physics				
Frequency: Winter semester	**Duration:** One semester	**Semester:** Third semester	**Credits:** 6	**Work load:** 150 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Research	Res	6	4
2	**Language:** English				
3	**Content** This course aims to prepare the students for the thesis work. Researchers and professors from the three universities and the associated partners are invited to give a seminar of about two hours to present their research activities and possible opportunities for the internship in preparation for the final exam. It is planned to have a maximum of 15 seminars. Students will be invited to deepen their knowledge by studying extra materials provided during the lectures.				
4	**Learning outcome** At the end of the course, the student will know all the research opportunities offered for the thesis as well as the basic knowledge necessary to conduct research work and write the final document.				
5	**Teaching methods** Lecture (100%)				
6	**Examination** Graded module				
7	**Coursework and examination requirements** Coursework: None. Examination: Report.				
8	**Prerequisites** Basic knowledge of particle physics				
9	**Recommended literature** Will be specified by the speaker				
10	**Module type** Compulsory module				
11	**Responsible** Prof. Dr. Angelo Carbone	**Organization** University of Bologna, Department of Physics			

Modules of the fourth semester

The modules of the fourth semester are offered by TUDO, but can be worked on at either of the universities or partner institutions. The only compulsory module is the final examination worth 12 ECTS credits that will take place at TUDO. Students will need to choose from one of the elective modules which are associated with research conducted at the university, a research laboratory or a company, and which each correspond to 18 credits. The result of all three modules is a Master thesis.

Compulsory modules

No.	Module	ECTS	Graded
IMAPP-04-01	Final examination	12	Yes

Elective modules

No.	Module	ECTS	Graded
IMAPP-04-02	Preparation for the final examination	18	Yes
IMAPP-04-03	Preparation abroad for the final examination	18	Yes
IMAPP-04-04	Internship in preparation for the final examination	18	Yes
IMAPP-04-05	Internship abroad in preparation for the final examination	18	Yes

Final examination (IMAPP-04-01)				
Degree program: Advanced Methods in Particle Physics				
Frequency: Summer semester	**Duration:** One semester	**Semester:** Fourth semester	**Credits:** 12	**Work load:** 300 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Examination	Ex	12	n.a.
2	**Language:** English				
3	**Content** Discussion of the research project and the related fields.				
4	**Learning outcome** Students will be able to explain and defend their research results and methods in front of an expert audience.				
5	**Teaching methods** Seminar (50%) and directed discussion (50%)				
6	**Examination** Graded module				
7	**Coursework and examination requirements** Coursework: None. Examination: Oral examination.				
8	**Prerequisites** Any of the preparatory modules IMAPP-04-02, IMAPP-04-03, IMAPP-04-04, IMAPP-04-05.				
9	**Recommended literature** None				
10	**Module type** Compulsory module				
11	**Responsible** Prof. Dr. Kevin Kröninger	**Organization** TU Dortmund University, Department of Physics			

Preparation for the final examination (IMAPP-04-02)				
Degree program: Advanced Methods in Particle Physics				
Frequency: Summer semester	**Duration:** One semester	**Semester:** Fourth semester	**Credits:** 18	**Work load:** 450 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Supervised research	Res	18	n.a.
2	**Language:** English				
3	**Content** The preparation of the final examination is devoted to activities of higher formation, in the field of scientific research or technological advances, to be carried out in a research Laboratory of one the university partners.				
4	**Learning outcome** The student develops an experimental, computational and/or theoretical work on a topic which is at the frontier of science, containing an advanced application of the investigation methodologies of the chosen curriculum and yielding a deepening in the sector of specialization.				
5	**Teaching methods** Research				
6	**Examination** Graded module				
7	**Coursework and examination requirements** Coursework: None. Examination: Graded Master thesis.				
8	**Prerequisites** See examination regulation				
9	**Recommended literature** Specialized literature will be provided by the supervisor				
10	**Module type** Elective module				
11	**Responsible** Prof. Dr. Kevin Kröninger	**Organization** TU Dortmund University, Department of Physics			

Preparation abroad for the final examination (IMAPP-04-03)

Degree program: Advanced Methods in Particle Physics

Frequency:	**Duration:**	**Semester:**	**Credits:**	**Work load:**
Summer semester	One semester	Fourth semester	18	450 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Supervised research	Res	18	n.a.
2	**Language:** English				
3	**Content** The preparation of the final examination is devoted to activities of higher formation, in the field of scientific research or technological advances, to be carried out in a Department or research Laboratory abroad.				
4	**Learning outcome** The student develops an experimental, computational and/or theoretical work on a topic which is at the frontier of science, containing an advanced application of the investigation methodologies of the chosen curriculum and yielding a deepening in the sector of specialization.				
5	**Teaching methods** Research				
6	**Examination** Graded module				
7	**Coursework and examination requirements** Coursework: None. Examination: Graded Master thesis.				
8	**Prerequisites** See examination regulation				
9	**Recommended literature** Specialized literature will be provided by the supervisor				
10	**Module type** Elective module				
11	**Responsible** Prof. Dr. Kevin Kröninger	**Organization** TU Dortmund University, Department of Physics			

Internship in preparation for the final examination (IMAPP-04-04)				
Degree program: Advanced Methods in Particle Physics				
Frequency: Summer semester	**Duration:** One semester	**Semester:** Fourth semester	**Credits:** 18	**Work load:** 450 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Supervised research	Res	18	n.a.
2	**Language:** English				
3	**Content** In preparation for the final examination, the student performs activities in the field of scientific research or technological advances, to be carried out at study centers, public (research agencies, schools, hospitals, ...) and private agencies or companies.				
4	**Learning outcome** The student carries out a specific work, under the supervision of an external tutor, aimed at refining his/her learning skills and professional formation.				
5	**Teaching methods** Research				
6	**Examination** Graded module				
7	**Coursework and examination requirements** Coursework: None. Examination: Graded Master thesis.				
8	**Prerequisites** See examination regulation				
9	**Recommended literature** Specialized literature will be provided by the supervisor				
10	**Module type** Elective module				
11	**Responsible** Prof. Dr. Kevin Kröninger		**Organization** TU Dortmund University, Department of Physics		

Internship abroad in preparation for the final examination (IMAPP-04-05)				
Degree program: Advanced Methods in Particle Physics				
Frequency: Summer semester	**Duration:** One semester	**Semester:** Fourth semester	**Credits:** 18	**Work load:** 450 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Supervised research	Res	18	n.a.
2	**Language:** English				
3	**Content** In preparation for the final examination, the student performs activities in the field of scientific research or technological advances, to be carried out at study centers, public and private agencies or companies, abroad.				
4	**Learning outcome** The student carries out a specific work, under the supervision of an external tutor, aimed at refining his/her learning skills and professional formation.				
5	**Teaching methods** Research				
6	**Examination** Graded module				
7	**Coursework and examination requirements** Coursework: None. Examination: Graded Master thesis.				
8	**Prerequisites** See examination regulation				
9	**Recommended literature** Specialized literature will be provided by the supervisor				
10	**Module type** Elective module				
11	**Responsible** Prof. Dr. Kevin Kröninger		**Organization** TU Dortmund University, Department of Physics		