Handbook of Modules

MSc Physics

Department of Physics
School of Science and Technology,
University of Siegen

Contents

1 Structure of the MSc program

The program for the MSc in Physics is structured modularly and comprises a one-year phase of attending courses followed by a one-year research phase. The work load for single modules is specified using credit points (CP) according to the European credit transfer and accumulation system (ECTS). For the complete master program the workload totals to 120 CP.

The curriculum is subdivided into the following sections:

(a) Specialization area (in total 24 CP). At the end of the first year, students take an oral exam on the topics of the specialization area.

(b) Free elective modules (in total 21 CP).

(c) Lab course (1 module, 9 CP).

(d) Master seminar (1 module, 6 CP).

(e) Research phase, Master thesis (3 modules, in total 60 CP).

Modules can, in principle, be completed in any possible order, yet in practice this will depend on when courses are offered. Core modules are offered on a yearly basis, either in summer or winter term and may be chosen for the specialization area or the free elective modules. The module descriptions specify the language in which the module is envisaged to be held. The choice of language is, however, not fixed and depends on the language skills of the audience.

The following table illustrates the structure of a possible curriculum:

1. Semester	2. Semester	3. Semester	4. Semester
Core module Specialization area 4Lec/2Ex (**9**)	Elective Specialization area 2Lec/2Ex (**6**)	**Oral Exam** Specialization area (**–**)	
	Core module Specialization area 4Lec/2Ex (**9**)		
Elective 2Lec/2Ex (**6**)	Elective 2Lec/2Ex (**6**)		
Elective 2Lec/2Ex (**6**)	Elective 1Lec/1Ex (**3**)		
Master lab course 4P (**9**)	Master seminar 2S (**6**)	Preparation & training for MSc thesis (**15+15**)	**Master thesis** (**30**)
(**30**)	(**30**)	(**30**)	(**30**)

In chapter 3 different arrangements for the curriculum are illustrated by means of exemplary curricula.

2 Module catalogue

2.1 Core modules

Core modules comprise four hours of lectures per week that are accompanied by two hours of exercise classes per week. Core modules are assessed with 9 CP and are offered on a yearly basis. They are based on the research areas of the department.

1. **Experimental Physics (M-E)**

(a) Experimental solid state physics (winter semester)
(b) Experimental quantum optics (summer semester)
(c) Experimental particle physics (summer semester)

2. **Theoretical Physics (M-T)**

   (a) Quantum information theory / Foundations of quantum mechanics (annually alternating, summer semester)
   (b) Theoretical particle physics I (summer semester)
   (c) Theoretical particle physics II (winter semester)

2.2 Electives

All courses in the physics department may be chosen as electives. They may vary in scope and are assessed with 3, 6 or 9 CP, depending on the work load. Below, six different groups of electives are listed. In every year at least one course will be offered in every group.

It should be stressed that besides the courses listed below, also core modules and other optional courses offered by the department can be chosen as electives. Also, other modules offered by the School of Science and Technology (e.g., in mathematics) are routinely accepted as electives. In this case, however, a consultation with the chairman of the examination office (contact see below) is required.

A. **Methods of experimental physics (M-WA)**

   (1) Statistical methods for data analysis
   (2) Electronics lab course
   (3) Detector physics
   (4) Accelerator physics II

B. **Solid state physics (M-WB)**

   (1) Modern methods of X-ray scattering
   (2) Solid state physics in nanoscience
   (3) Theoretical solid state physics

C. **Quantum optics and nano optics (M-WC)**

   (1) Laser spectroscopy
   (2) Nano optics
   (3) Experimental methods of quantum and nano optics
   (4) Quantum theory of light
   (5) Mathematics of quantum mechanics
   (6) Quantum effects and quantum paradoxa

D. **Experimental particle and astro-particle physics (M-WD)**

   (1) Astroparticle physics
   (2) Cosmology
   (3) Physics at the Pierre Auger Observatory
   (4) Physics at the LHC

E. **Theoretical particle physics (M-WE):** Phenomenology of the Standard Model

(1) Flavour physics

(2) Hadron physics

(3) Collider physics

(4) Higgs physics

F. **Theoretical particle physics (M-WF):** Advanced topics

(1) Physics beyond the Standard Model

(2) Effective field theories

(3) Tools for the calculation of loop diagrams

(4) Specific topics in quantum field theory

2.3 Mandatory modules

The mandatory section of the curriculum consists of the master laboratory course (9 CP), the MSc seminar (6 CP) and the one-year research phase (Preparation 15 CP, Thesis training 15 CP, MSc thesis 30 CP).

2.4 List of Modules

Token	Module name	CP
M-E1	Experimental solid state physics	9
M-E2	Experimental quantum optics	9
M-E3	Experimental particle physics	9
M-T1	Quantum information theory	9
M-T2	Foundations of quantum mechanics	9
M-T3	Theoretical particle physics I	9
M-T4	Theoretical particle physics II	9
M-WA1	Statistical methods for data analysis	9
M-WA2	Electronics lab course	6
M-WA3	Detector physics	6
M-WA4	Accelerator physics II	3
M-WB1	Modern methods of X-ray scattering	6
M-WB2	Solid state physics in nanoscience	6
M-WB3	Theoretical solid state physics	6
M-WC1	Laser spectroscopy	6
M-WC2	Nano optics	6
M-WC3	Experimental methods of quantum and nano optics	6
M-WC4	Quantum theory of light	6
M-WC5	Mathematics of quantum mechanics	3
M-WC6	Quantum effects and quantum paradoxa	6
M-WD1	Astroparticle physics	6
M-WD2	Cosmology	6
M-WD3	Physics at the Pierre Auger Observatory	6
M-WD4	Physics at the LHC	6
M-WE1	Flavour physics	6
M-WE2	Hadron physics	6
M-WE3	Collider physics	6
M-WE4	Higgs physics	6
M-WF1	Physics beyond the Standard Model	6
M-WF2	Effective field theories	6
M-WF3	Tools for the calculation of loop diagrams	6
M-WF4	Specific topics in quantum field theory	3
M-P	Master lab course	9
M-S	Master seminar	6
M-AV	Research preparation project	15
M-AE	Thesis training project	15
M-A	Master thesis	30

3 Exemplary curricula

The freedom of choice in the specialization area and the free elective modules allow individual specialization in the research fields of the department. Note, however, that the weight of experimental modules (as measured by their CPs) in the specialization area and the free electives, needs to be at least 9CP in total. Analogously, the theoretical courses also need to have a minimum weight of 9 CPs. In the following, some exemplary curricula are listed.

Specialization: Experimental quantum optics and quantum information processing

1. Semester	2. Semester	3. Semester	4. Semester
Electives Laser spectroscopy 2Lec/2Ex (**6**)	Core module Exp. Quantum optics 4Lec/2Ex (**9**)	**Exam** Exp. Quantum optics (**–**)	
	Core module Quantum inform. theory 4Lec/2Ex (**9**)		
Electives Exp. methods of QO/NO 2Lec/2Ex (**6**)	Electives Nano optics 2Lec/2Ex (**6**)		
Electives Data analysis 3Lec/3Ex (**9**)			
Master lab course 4P (**9**)	Master seminar Quantum Optics 2S (**6**)	Prep.+training for master thesis (**15+15**)	**Master thesis** Exp. Quantum optics (**30**)
(**30**)	(**30**)	(**30**)	(**30**)

Specialization: Experimental particle and astro-particle physics

1. Semester	2. Semester	3. Semester	4. Semester
Core module Exp. particle physics 4Lec/2Ex (**9**)	Electives Detector physics 2Lec/2Ex (**6**)	**Exam** Exp. particle physics (**–**)	
Core module Theo. particle physics I 4Lec/2Ex (**9**)			
Electives Physics at the LHC 2Lec/2Ex (**6**)	Electives Data analysis 3Lec/3Ex (**9**)		
	Electives Astroparticle physics 2Lec/2Ex (**6**)		
Master seminar Particle physics 2S (**6**)	Master lab course 4P (**9**)	Prep.+training for master thesis (**15+15**)	**Master thesis** Exp. particle physics (**30**)
(**30**)	(**30**)	(**30**)	(**30**)

Specialization: Experimental solid state physics

1. Semester	2. Semester	3. Semester	4. Semester
Core module Exp. solid state physics 4Lec/2Ex (**9**)	Electives SSP of nano structures 2Lec/2Ex (**6**)	**Exam** Exp. solid state physics (**–**)	
	Core module Quantum inform. theory 4Lec/2Ex (**9**)		
Electives X-ray physics 2Lec/2Ex (**6**)	Electives Condensed matter theory 2Lec/2Ex (**6**)		
Electives Nano optics 2Lec/2Ex (**6**)	Electives Accelerator physics II 1Lec/1Ex (**3**)		
Master lab course 4P (**9**)	Master seminar Festkörperphyik 2S (**6**)	Prep.+training for master thesis (**15+15**)	**Master thesis** Exp. solid state physics (**30**)
(**30**)	(**30**)	(**30**)	(**30**)

Specialization: Experimental physics

1. Semester	2. Semester	3. Semester	4. Semester
Core module Exp. Quantum optics 4Lec/2Ex (**9**)	Electives Exp. methods of QO/NO 2Lec/2Ex (**6**)	**Exam** Exp. Quantum optics (**–**)	
	Core module Exp. solid state physics 4Lec/2Ex (**9**)		
Core module Exp. particle physics 4Lec/2Ex (**9**)	Core module Theo. particle physics I 4Lec/2Ex (**9**)		
Electives Accelerator physics II 1Lec/1Ex (**3**)			
Master seminar Experimental Physics 2S (**6**)	Master lab course 4P (**9**)	Prep.+training for master thesis (**15+15**)	**Master thesis** Exp. Quantum optics (**30**)
(**27**)	(**33**)	(**30**)	(**30**)

Specialization: Theoretical quantum optics

Remark: One of the core modules ’Quantum information theory’ (M-T1) and ’Foundations of quantum mechanics’ (M-T2) may already be completed in the sixth semester of the bachelor program.

1. Semester	2. Semester	3. Semester	4. Semester
Electives Quantum theory of light 2Lec/2Ex **(6)**	Core module Quantum inform. theory 4Lec/2Ex **(9)**	**Exam** Theo. Quantum optics **(–)**	
	Core module Exp. Quantum optics 4Lec/2Ex **(9)**		
Electives Laser spectroscopy 2Lec/2Ex **(6)**	Electives Cosmology 2Lec/2Ex **(6)**		
Electives Condensed matter theory 2Lec/2Ex **(6)**	Electives Mathematics of QM 1Lec/1Ex **(3)**		
Master lab course 4P **(9)**	Master seminar Quantum Optics 2S **(6)**	Prep.+training for master thesis **(15+15)**	**Master thesis** Theo. Quantum optics **(30)**
(**27**)	(**33**)	(**30**)	(**30**)

Specialization: Theoretical particle physics

Remark: The course ’Theoretical particle physics I’ (M-T3) may already be completed in the sixth semester of the bachelor program.

1. Semester	2. Semester	3. Semester	4. Semester
Core module Theo. particle physics II 4Lec/2Ex **(9)**	Electives Flavour physics 2Lec/2Ex **(6)**	**Exam** Theo. particle physics **(–)**	
	Core module Exp. particle physics 4Lec/2Ex **(9)**		
Electives Hadron physics 2Lec/2Ex **(6)**	Electives Physics at the LHC 2Lec/2Ex **(6)**		
Electives Detector physics 2Lec/2Ex **(6)**	Electives Special topics of QFT 1Lec/1Ex **(3)**		
Master lab course 4P **(9)**	Master seminar Particle physics 2S **(6)**	Prep.+training for master thesis **(15+15)**	**Master thesis** Theo. particle physics **(30)**
(**30**)	(**30**)	(**30**)	(**30**)

Specialization: Theoretical physics

1. Semester	2. Semester	3. Semester	4. Semester
Core module Theo. particle physics II 4Lec/2Ex (**9**)	Electives Collider physics 2Lec/2Ex (**6**)	**Exam** Theo. particle physics (**–**)	
	Core module Quantum inform. theory 4Lec/2Ex (**9**)		
Electives Higgs physics 2Lec/2Ex (**6**)	Core module Exp. particle physics 4Lec/2Ex (**9**)		
Electives Physics beyond the SM 2Lec/2Ex (**6**)			
Master lab course 4P (**9**)	Master seminar Theoretical Physics 2S (**6**)	Prep.+training for master thesis (**15+15**)	**Master thesis** Theo. particle physics (**30**)
(**30**)	(**30**)	(**30**)	(**30**)

Specialization: Mathematical physics

1. Semester	2. Semester	3. Semester	4. Semester
Electives Quantum theory of light 2Lec/2Ex (**6**)	Core module Fundamentals of QM 4Lec/2Ex (**9**)	**Exam** Theo. Quantum optics (**–**)	
	Core module Exp. Quantum optics 4Lec/2Ex (**9**)		
Electives Mathematics of QM 1Lec/1Ex (**3**)	Electives Functional analysis II 4Lec/2Ex (**9**)		
Electives Functional analysis I 4Lec/2Ex (**9**)			
Master lab course 4P (**9**)	Master seminar Theoretical Physics 2S (**6**)	Prep.+training for master thesis (**15+15**)	**Master thesis** Theo. Quantum optics (**30**)
(**27**)	(**33**)	(**30**)	(**30**)

4 Module descriptions: Core modules

4.1 Experimental Physics (M-E)

Course title	Experimental solid state physics
Subtitle (if any)	
Abbreviation	M-E1
Code	4PHY20011V, 4PHY20012V
Language	English
Regular cycle	winter semester
Duration	1 Semester
Responsible lecturer	Lecturers of experimental solid state physics
Teaching format	Lecture: 4 hours/week, tutorial 2 hours/week
Work load	270 h (90 h lectures and tutorials, 180 h self-study)
Credit points	9
Prerequisites for participation	none
Teaching goals	The students are exposed to current topics of solid state physics with the help of selected examples. The necessary expertise for a subsequent master thesis is conveyed. In the tutorial the students solve problems, deepening their understanding of the material. From this they learn to recognize physical problems, to put them into relation to the lecture material, to formulate them in mathematical terms and finally to find solutions. Discussing these steps with classmates and tutors promotes understanding and the development of communication skills about physical matters.
Course description	Electronic structure of solids, Drude model, Sommerfeld model, band structure, Kronig-Penney-Model, Band structure of selected metals Optical properties of conductors, plasmons Bloch functions, Bloch oscillations, Weak and Tight-Binding methods, Motion of electrons in solids, effective mass, transport phenomena, Boltzmann equation, electrical conductivity of metals, semiconductors Wiedemann-Franz law, Seebeck and Peltier effect Semiconductors, doping, thermal and electronic properties, pn-junction, transport equation and transport processes Electrons in magnetic fields, Landau levels, de Haas - van Alphen effect, Quantum-Hall-effect Quantum mechanical treatment of exchange interaction, magentism, spin-orbit coupling, Band magnetism, Stoner model, experimental determination of magnetic structures, Dzyaloshinskii-Moriya interaction, skyrmions ultrafast magnetization dynamics Ginzburg-Landau theory of phase transitions Criticality, phase diagrams, spinodals structure and dynamics of soft matter
Assessment method	Written or oral exam
Prerequisite for the award of credit points	Passed exam
Usability of module	
Teaching style	Lecture with blackboard, electronic media, exercises for self-study.
Literature	Chaikin, Lubensky: Principles of condensed matter physics Ashcroft, Mermin: Solid state physics Dresselhaus: Solid state properties

Course title	Experimental Quantum Optics
Subtitle (if any)	
Abbreviation	M-E2
Code	4PHY20021V, 4PHY20022V
Language	English
Regular cycle	summer semester
Duration	1 semester
Responsible lecturer	Prof. Dr. Ch. Wunderlich
Teaching format	Lecture: 4 hours/week, Tutorial: 2 hours/week
Work load	270 h (90 h lectures and tutorials, 180 h self-study)
Credit points	9
Prerequisites for participation	none
Teaching goals	The students will learn about selected fundamental experiments and theoretical concepts of modern quantum optics and they will be provided with the necessary technical skills to start a master's thesis. Within tutorials, the students will learns to recognize physics problems, to relate them to the course topics, to phrase them mathematically and finally to find a solution. The discussion af the aforementioned steps with other students as well as with teachers will deepen the understanding and develop communications skills for scientific discussions.
Course description	Quantization of the electromagnetic field Coherent states, squeezed states Correlation functions Interferometer Semi-classical / quantized light-matter-interaction, dressed states Decoherence Cavity-quantum-electrodynamics Trapped atoms, ions, molecules Laser cooling Bose-Einstein-Condensation Entanglement Fundamentals of quantum information processing Fundamentals of quantum metrology and sensing
Assessment method	Written or oral exam
Prerequisite for the award of credit points	Passed exam
Usability of the module	M-WC1, M-WC2, M-WC3, M-WC4
Teaching style	Lecture with blackboard and electronic media, exercises for self-study.
Literature	Bachor: A Guide to Experiments in Quantum Optics Fox: Quantum Optics Gerry, Knight: Introductory Quantum Optics Grynberg, Aspect, Fabre: Introduction to Quantum Optics Haroche, Raimond: Exploring the Quantum Schleich: Quantum Optics in Phase Space

Course title	Experimental particle physics
Subtitle (if any)	
Abbreviation	M-E3
Code	4PHY20031V, 4PHY20032V
Language	German
Regular cycle	summer semester
Duration	1 semester
Responsible lecturer	Lecturers from research area experimental particle physics
Teaching format	Lecture: 4 hours/week, tutorial: 2 hours/week
Work load	270 h (90 h lectures and tutorials, 180 h self-study)
Credit points	9
Prerequisites for participation	none
Teaching goals	The students are guided towards the forefront of research by focussing on selected topics. The necessary concepts and tools are provided such that the students are well prepared for taking the initial steps of a master thesis. In the accompanying exercises, the students learn to identify physical problems, relate them to the content of the lecture, find mathematical formulations and their solutions. Discussing these issues with fellow students and tutors deepens the understanding and helps developing the students' ability to communicate physics issues.
Course description	Standard models of particle physics Calculation of cross sections Quark-parton model, structure functions Physics of heavy quarks Key experiments related to the standard model Physics beyond the standard model
Assessment method	Written or oral exam
Prerequisites for the award of credit points	Passed exam
Usability of the module	M-WA3, M-WD1, M-WD2, M-WD3, M-WD4, M-WE1
Teaching style	Lecture with blackboard, electronic media, exercises for self-study
Literature	Berger: Elementarteilchenphysik Griffiths: Introduction to Elementary Particles

4.2 Theoretical Physics (M-T)

Course title	Quantum information theory
Subtitle (if any)	
Abbreviation	M-T1
Code	4PHY20111V, 4PHY20112V
Language	English
Regular cycle	summer semester (annually changing with M-T2)
Duration	1 semester
Responsible lecturer	Prof. Dr. O. Gühne
Teaching format	Lecture: 4 hours/week, tutorial: 2 hours/week
Work load	270 h (90 h lectures and tutorials, 180 h self-study)
Credit points	9
Prerequisites for participation	none
Teaching goals	The students learn the advanced theoretical concepts of classical and quantum information theory. This enables them to view physical problems from the perspective of algorithmic complexity. In the tutorial the students solve problems, deepening their understanding of the material. From this they learn to recognize physical problems, to put them into relation to the lecture material, to formulate them in mathematical terms and finally to find solutions. Discussing these steps with classmates and tutors promotes understanding and the development of communication skills about physical matters.
Course description	Protocols of quantum information: cryptography, teleportation, etc. Security of quantum cryptography Quantum computers and quantum algorithms Quantum error correction Complexity classes P, NP, BQP, QMA Measurement-based quantum computation Topological quantum information processing
Assessment method	Written or oral exam, in addition possibly a presentation on a recent research paper.
Prerequisite for the award of credit points	Passed exam
Usability of the module	
Teaching style	Lecture with blackboard, exercises for self-study.
Literature	Nielsen, Chuang: Quantum Information Theory Barnett: Quantum Information Recent research publications

Course title	Foundations of Quantum Mechanics
Subtitle (if any)	
Abbreviation	M-T2
Code	4PHY20121V, 4PHY20122V
Language	English
Regular cycle	summer semester (annually changing with M-T2)
Duration	1 semester
Responsible lecturer	Prof. Dr. O. Gühne
Teaching format	Lecture: 4 hours/week, tutorial: 2 hours/week
Work load	270 h (90 h lectures and tutorials, 180 h self-study)
Credit points	9
Prerequisites for participation	none
Teaching goals	The students learn about the mathematical, physical, and philosophical problems in the foundations of quantum mechanics. This brings them in connection to current research. In the tutorial the students solve problems, deepening their understanding of the material. From this they learn to recognize physical problems, to put them into relation to the lecture material, to formulate them in mathematical terms and finally to find solutions. Discussing these steps with classmates and tutors promotes understanding and the development of communication skills about physical matters.
Course description	Quantum formalism Theorems from Gleason, Kochen-Specker and Bell Non-locality and the EPR argument Entanglement theory Interpretation of the wave function Measurements in quantum mechanics
Assessment method	Written or oral exam, in addition possibly a presentation on a recent research paper.
Prerequisite for the award of credit points	Passed exam
Usability of the module	
Teaching style	Lecture with blackboard, exercises for self-study.
Literature	Peres: Quantum Theory Recent research publications

Course title	Theoretical particle physics I
Subtitle (if any)	Quantum field theory and the basics of the Standard Model
Abbreviation	M-T3
Code	4PHY20131V, 4PHY20132V
Language	English
Regular cycle	every summer semester
Duration	1 semester
Responsible lecturer	lecturer in theoretical particle physics
Teaching format	Lecture: 4 hours/week, tutorial: 2 hours/week
work load	270 h (90 h lectures and tutorials, 180 h self-study)
Credit points	9
Prerequisites for participation	none
Teaching goals	Students will learn the fundamental concepts of quantum field theory as the mathematical and physical foundation of not only particle physics, but also quantum optics and collective phenomena. A deeper understanding will be achieved through exercises, in which modelling and solutions of concrete quantum-field theoretical systems are discussed.
Course description	Representations of the Lorentz group Quantisation of free fields, fermions und bosons Klein-Gordon and Dirac equations Lagrangians und the Noether theorem Interacting fields, perturbation theory and Feynman diagrams ϕ^4-theory and quantum electrodynamics Calculation of cross sections and decay rates Basics of the Standard Model, Higgs mechanism
Assessment method	Written or oral exam
Requirement for the award of credit points	Passed exam
Usability of the module	M-E3, M-T4, M-WD4, M-WE1, M-WE4
Teaching style	Lectures on blackboard, exercises for self-study
Literature	Peskin, Schroeder: Introduction to Quantum Field Theory Schwartz: Quantum Field Theory and the Standard Model Itzykson, Zuber: Quantum Field Theory Ryder: Quantum Field Theory Weinberg: Quantum Field Theory I

Course title	Theoretical particle physics II
Subtitle (if any)	Advanced quantum field theory and radiative corrections within the Standard Model
Abbreviation	M-T4
Code	4PHY20141V, 4PHY20142V
Language	English
Regular cycle	every winter semester
Duration	1 semester
Responsible lecturer	lecturer in theoretical particle physics
Teaching format	Lecture: 4 hours/week, tutorial: 2 hours/week
work load	270 h (90 h lectures and tutorials, 180 h self-study)
Credit points	9
Prerequisites for participation	M-T3
Teaching goals	Students will understand the theoretical concepts that are necessary for the quantisation of gauge theories in particular. An important part is the derivation of correlation functions within the formalism of path integrals and symmetry considerations. The students will learn about the renormalisation of fields and composite operators within the framework of the Standard Model, and will be equipped with the necessary mathematical methods to compute loop integrals. They will be able to apply these methods to the calculation of precise predictions of elementary observables in particle physics.
Course description	Path integral formalism, effective action Symmetries and Ward-Takahashi identities Quantisation of non-abelian gauge theories Fadeev-Popov ghosts and BRST-symmetry Loop integrals and renormalisation Operator product expansion Hadronic structure functions and parton distribution functions Applications to elementary Standard Model processes at the LHC
Assessment method	Written or oral exam
Requirement for the award of credit points	Passed exam
Usability of the module	M-WE2, M-WE3, M-WF1, M-WF2, M-WF3, M-WF4
Teaching style	Lectures on blackboard, exercises for self-study
Literature	Peskin, Schroeder: Introduction to Quantum Field Theory Schwartz: Quantum Field Theory and the Standard Model Weinberg: Quantum Field Theory II Collins: Renormalization Donoghue, Golowich, Holstein: Dynamics of the Standard Model Ellis, Stirling, Webber: QCD and Collider Physics

5 Module description: Electives

5.1 Methods of experimental physics (M-WA)

Course title	Statistical methods for data analysis
Subtitle (if any)	
Abbreviation	M-WA1
Code	4PHY91011V, 4PHY91012V
Language	German
Regular cycle	annually at least one module of M-WA
Duration	1 semester
Responsible lecturer	Prof. Dr. P. Buchholz
Teaching format	Lecture: 3 hours/week, tutorial: 3 hours/week
Work load	270 h (90 h lectures and tutorials, 180 h self-study)
Credit points	9
Prerequisites for participation	None
Teachings goals	The students learn the basics of data analysis and the application of more complex statistical methods. The skills to solve typical questions regarding data analyis occurring as a part of a bachelor- or master thesis are taught.
Course description	Description of data, descriptive statistics Basic concepts and terms of statistics Probability density distributions Monte Carlo method Parameter estimation Hypothesis testing Confidence intervals and exclusion limits Classification of events Systematic uncertainties Multivariate methods
Assessment method	Written or oral exam
Prerequisite for the award of credit points	Passed exam
Usability of the module	
Teaching style	Lecture with blackboard, electronic media, exercises for self-study, practical training with data analysis software on the computer.
Literature	Barlow: Statistics – A Guide to the Use of Statistical Methods in the Physical Sciences Bevan: Statistical Data Analysis for the Physical Sciences Blobel, Lohrmann: Statistische und numerische Methoden der Datenanalyse Bohm, Zech: Introduction to Statistics and Data Analysis for Physicists Brandt: Datenanalyse für Naturwissenschaftler und Ingenieure Cowan: Statistical Data Analysis

Course title	Electronic lab course
Subtitle (if any)	
Abbreviation	M-WA2
Code	4PHY91021V, 4PHY91022V
Language	German
Regular cycle	winter semester
Duration	1 semester
Responsible lecturer	Prof. Dr. P. Buchholz
Teaching format	Lecture: 2 hours/week, tutorial: 4 hours/week
Work load	180 h (90 h lectures and tutorials, 90 h self-study)
Credit points	6
Prerequisites for participation	none
Teaching goals	The students will be familiarized with the basics of electronics. For this purpose, the course consists of lecture and practical parts. The former one conveys the theoretical basics while in the latter experiments are carried out. The electronic circuits to be examined will be set up and simulated with PSPICE in parallel. Students will learn the handling of electronic components as well as CAD-programs. The critical comparison of the measurements at the electronic circuits with the simulations is a further goal of this course.
Course description	Introduction to PSPICE Passive components: resistor, capacitor, coil Introduction to semiconductor physics Diode circuits Transistor circuits Field-effect transistors Operational amplifiers
Assessment method	Written or oral exam
Prerequisite for the award of credit points	Passed exam
Usability of the module	
Teaching style	Lecture with blackboard, electronic media, computer simulation and practical exercises with discrete components.
Literature	Duyan, Hahnloser, Traeger: PSPICE Hering, Bressler, Gutekunst: Elektronik für Ingenieure Horowitz, Hill: The Art of Electronics Tietze, Schenk: Halbleiter-Schaltungstechnik v.Wangenheim: PC-Simulation elektronischer Grundschaltungen

Course title	Detector Physics
Subtitle (if any)	
Abbreviation	M-WA3
Code	4PHY91031V, 4PHY91032V
Language	English
Regular cycle	annually at least one course of M-WA
Duration	1 semester
Responsible lecturer	Prof. Dr. I. Fleck
Teaching format	Lecture: 3 hours/week, tutorial: 1 hour/week
Work load	180 h (60 h lectures and tutorials, 120 h self-study)
Credit points	6
Prerequisites for participation	none
Teaching goals	The students get familiar with the foundations of detector physics. They learn to understand the working principle of detectors and the physical principles responsible for generating signals. They learn about the fields of application of different kinds of detectors.
Course description	Interaction of particles and matter Properties of detectors Gas filled detectors Solid-state detectors Particle identification Medical applications
Assessment method	Written or oral exam
Prerequisite for the award of credit points	Passed exam
Usability of the module	
Teaching style	Lecture with blackoard, electronic media, Tutorials with exercises for self-study.
Literature	Grupen, Schwartz: Particle Detectors Grupen, Buvat: Handbook of Particle Detection and Imaging Kolanowksi, Wermes: Teilchendetektoren

Course title	Accelerator physics II
Subtitle (if any)	Superconducting HF systems
Abbreviation	M-WA4
Code	4PHY91041V, 4PHY91042V
Language	German
Regular cycle	annually at least one module of M-WA
Duration	1 semester
Responsible lecturer	Prof. Dr. J. Knobloch
Teaching format	Lecture: 1 hour/week, lab course: 1 hour/week (block course)
Work load	90 h (30 h lectures and lab courses, 60 h self-study)
Credit points	3
Prerequisites for participation	none
Teaching goals	Based on general accelerator physics, the students are acquainted with the foundations of superconducting HF (SRF) – a key technology for many modern accelerators. To do so, the fundamentals are taught using lectures as well as computer-assisted simulations. The students acquire the ability to work on topics in the realm of accelerator physics and SRF for their master theses.
Course description	Review of copper cavities and their limitations (loss, HOMs) Advantages of superconducting resonators Introduction to superconductivity and the theory of superconducting HF systems Limitations of SRF resonators in practice and solutions Production and handling of SRF systems Components for the operation of SRF cavities in accelerators Lab course: Simulations and optimization of SRF systems
Assessment method	Written lab report.
Prerequisite for the award of credit points	Approved lab report
Usability of the module	
Teaching style	Lecture with blackboard, electronic media, exercises for self-study.
Literature	Padamsee, Knobloch, Hays: Superconducting RF for Particle Accelerators

5.2 Solid state physics (M-WB)

Course title	Modern methods of X-ray scattering
Subtitle (if any)	
Abbreviation	M-WB1
Code	4PHY93011V, 4PHY93012V
Language	English
Regular cycle	annually at least one course of the elective subjects M-WB
Duration	1 semester
Responsible lecturer	Prof. Dr. C. Gutt
Teaching format	Lecture: 2 hours/week, tutorial: 2 hours/week
Work load	180 h (60 h lectures and tutorials, 120 h self-study)
Credit points	6
Prerquisites for participation	none
Teaching goals	The students know fundamental concepts of X-ray physics: they understand the origin of radiation and the physical mechanisms of interaction processes. The mathematical foundations for the description of interference phenomena in condensed matter are mastered and can be applied independently. The students understand how the atomic properties of condensed matter can be measured using X-rays. The knowledge of modern coherence-based and time-resolved methods enables the students to do a Bachelor or Master thesis in the field of research with synchrotron radiation sources or free electron lasers.
Course description	Within the framework of the module, the fundamentals of modern X-ray physics are to be developed. Interaction between X-rays and matter Absorption, scattering, hard and soft X-rays X-ray sources Tube, Synchrotron and Free Electron Lasers Diffraction at crystals, amorphous systems, nanostructures Laue equations, Ewald's sphere, diffraction methods Phonon spectroscopy, lattice vibrations, Debye–Waller factor Magnetic diffraction, XMCD effect, resonant scattering Coherence Ultra-fast X-ray diffraction Applications in Nanoscience
Assessment method	Written or oral exam
Prerequisite for the award of credit points	Passed exam
Usability of the module	
Teaching style	Lectures with blackboard, electronic media, exercises for self-study.
Literature	Als Nielsen, McMorrow: Modern Methods of X-ray Physics Warren: X-ray diffraction

Course title	Solid state physics in nanoscience
Subtitle (if any)	
Abbreviation	M-WB2
Code	4PHY93021V, 4PHY93022V
Language	English
Regular cycle	annually at least one corse of the elective subjects M-WB
Duration	1 semester
Responsible lecturer	Prof. Dr. C. Busse
Teaching format	Lecture: 2 hours/week, tutorial: 2 hours/week
Work load	180 h (60 h lectures and tutorials, 120 h self-study)
Credit points	6
Prerequisites for participation	none
Teaching goals	The students learn about concepts, methods and phenomena of solid state physics of nanostructures. These are also explained using the latest examples from current literature. The students learn how the reduction of dimensionality modifies the properties of solids. They will be able to estimate the size of the effects to be expected and to evaluate new phenomena with a view to possible applications. Furthermore, students learn to read and critically evaluate scientific literature. In the exercises the students learn to mathematically formulate and solve physical problems from the nanoworld. The discussion of the mentioned steps with fellow students and trainers promotes understanding and develops the ability to communicate about physical facts.
Course description	Electronic structure and density of states in 3D, 2D, 1D and 0D General solution of the Schrödinger equation in the potential well Quantum states in 1D and 0D nanostructures Surface crystallography Chemisorption and Physisorption, heterogeneous catalysis 2D materials (graphene, hexagonal boron nitride, transition metals of dichalcogenides) Dirac-like band structures Geometric structure and band structure of semiconductor nanostructures Influence of impurities and lattice distortions on the band structure of semiconductor nanostructures Excitons and charge carrier recombination Methods for the fabrication of nanostructures, thin films and two-dimensional materials X-ray crystallographic determination of the lattice structure High resolution microscopic methods (STM, AFM, SEM, TEM)
Assessment method	Oral exam
Prerequisite for the award of credit points	Passed exam
Usability of the module	
Teaching style	Lecture with blackboard, electronic media, exercises for self-study.
Literature	Oura et al.: Surface Science - An Introduction Harrison: Quantum Wells, Wires and Dots Grundman: The Physics of Semiconductors Bimberg: Semiconductor Nanostructures

Course title	Theoretical solid state physics
Subtitle (if any)	
Abbreviation	M-WB3
Code	4PHY94091V, 4PHY94092V
Language	English
Regular cycle	annually at least one corse of the elective subjects M-WB
Duration	1 semester
Responsible lecturer	Prof. Dr. W. Kilian
Teaching format	Lecture: 2 hours/week, tutorial: 2 hours/week
Work load	180 h (60 h lectures and tutorials, 120 h self-study)
Credit points	6
Prerequisites for participation	none
Teaching goals	The students know the fundamental theoretical concepts and methods of solid state physics. They are able to understand the many body quantum character of the physics involved and understand modern concepts of theoretical solid state science.
Course description	Quantum field theory for multi-particle interactions Path and field integral for bosons and fermions Matsubara formalism Perturbation theory Electron structure in solid state matter Superconduction
Assessment method	Written or oral exam
Prerequisite for the award of credit points	Passed exam
Usability of the module	
Teaching style	Lecture with blackboard, exercises for self-study.
Literature	Altland, Simmons: Condensed Matter Field Theory Mahan: Many-Particle Physics Zinn-Justin: Quantum Field Theory and Critical Phenomena

5.3 Quantum optics und Nano optics (M-WC)

Course title	Laser spectroscopy
Subtitle (if any)	
Abbreviation	M-WC1
Code	4PHY92011V, 4PHY92012V
Language	English
Regular cycle	winter semester
Duration	1 semester
Responsible lecturer	PD Dr. M. Johanning
Teaching format	Lecture: 2 hours/week, Tutorial: 2 hours/week
Work load	180 h (60 h lectures and tutorials, 120 h self-study)
Credit points	6
Prerequisites for participation	none
Teaching goals	The students will be introduced to the instruments and methods of laser spectroscopy. The knowledge of the energetic structure of atomic levels and its sensitivity to environmental quantities and light-matter interaction we will allow us to understand the atom as a probe. The students will learn to extract sample composition and state variables as pressure or temperature from the spectroscopic fingerprint. Modern application of laser spectrocopy for frequency standards or state manipulation will be covered.
Course description	Atoms, molecules and their interaction with light and in general with static and dynamic electromagnetic fields Coherent interaction, decoherence, optical Bloch equations and rate equations Basics of spectroscopic instrumentation: e. g. matrix optics, resonators, wavelength selection Lasers: coponents and properties, laser modes, cw and pulsed lasers, laser modulation Linear spectrocopy: absorption, emission, methods to improve sensitivity, determination of densities, fields, temperatures Non-linear spectrocopy: e. g. saturation spectrocopy, frequency mixing and harmonic generation Modern Laser applications: precision spectroscopy, frequency combs, laser cooling
Assessment method	Written or oral exam
Prerequisite for the award of credit points	Passed exam
Usability of the module	M-P, M-E2, M-WC2, M-WC3
Teaching style	Lecture with blackboard, experiments and electronic media, exercises for self-study.
Literature	Demtröder: Laser Spectroscopy Foot: Atomic Physics Fox: Quantum Optics Siegman: Lasers Suter: The Physics of Laser-Atom Interactions

Course title	Nano optics
Subtitle (if any)	
Abbreviation	M-WC2
Code	4PHY92021V, 4PHY92022V
Language	English
Regular cycle	annually at least one modules of the elective subjects M-WC
Duration	1 semester
Responsible lecturer	Prof. Dr. M. Agio
Teaching format	Lecture: 2 hours/week, tutorial: 2 hours/week
Work load	180 h (60 h lectures and tutorials, 120 h self-study)
Credit points	6
Prerequisites for participation	none
Teaching goals	Deepened knowledge of the fundamental phenomena of nano-optics, which are partly explained by experiments. The exercises train to recognise physical problems, to relate them to the lecture materiales, to formulate mathematically and to find solutions. The discussion of these steps with fellow students and trainers promotes understanding and develops the ability to communicate on physical issues.
Course description	Theoretical principles Propagation and focusing of optical fields Resolution and localisation Optical microscopy at nanoscale Optical interactions and quantum emitters Single-molecule spectroscopy Photonic Crystals Surface plasmon polaritons Optical antennas Optical forces
Assessment method	Written or oral exam
Prerequisite for the award of credit points	Passed exam
Usability of the module	M-E2, M-WC1, M-WC3, M-WC4
Teaching style	Lecture with blackboard, electronic media, exercises for self-study.
Literature	Novotny, Hecht: Principles of Nano-Optics Agio: Molecular Scattering and Fluorescence in Strongly Confined Optical Fields Lakowicz: Principles of Fluorescence Spectroscopy

Course title	Experimental methods in quantum- and nano-optics
Subtitle (if any)	
Abbreviation	M-WC3
Code	4PHY92031V, 4PHY92032V
Language	English
Regular cycle	annually one module from M-WC
Duration	1 semester
Responsible lecturer	Prof. Dr. M. Agio, Prof. Dr. C. Wunderlich
Teaching format	Lecture: 2 hours/week, Tutorial: 2 hours/week
Work load	180 h (60 h lectures and tutorials, 120 h self-study)
Credit points	6
Prerequisites for participation	none
Teaching goals	The students learn a range of fundamental experimental techniques which are essential in modern quantum- and nano-optics experiments. The insight into this repertoire of techniques makes it easier for students to start their own experiments as part of a master's thesis. In the exercises, partially in the laboratory, the students get hands-on expeirience with modern instruments.
Content	Spatially resolved single photon detection Temporal correlations in single photon detection Confocal microscopy Lock-In technique Acousto- and electro-optical modulation of Laser light Diode lasers, Laser systems Methods of Laser stabilization Generation of tailored radio-frequency pulses Vacuum technology Precise motion and position control
Assessment method	Written or oral exam
Prerequisite for the award of credit points	Passed exam
Usability of the module	M-E2, M-WC1, M-WC2, M-WC4
Medienformen	Lecture with blackboard and electronic media, exercises for self-study, hands-on practice in the laboratory, introductory tutorial for LabView programming.
Literature	Demtröder: Laser Spectroscopy Lakowicz: Principles of fluorescence spectroscopy Migdall, Fan, Bienfang: Single-Photon Generation and Detection

Course title	Quantum theory of light
Subtitle (if any)	
Abbreviation	M-WC4
Code	4PHY95011V, 4PHY95012V
Language	English
Cycle	one course in M-WC annually
Duration	1 semester
Responsible lecturer	Prof. Dr. O. Gühne
Teaching format	Lecture: 2 hours/week, Tutorial: 2 hours/week
Work load	180 h (60 h lectures and tutorials, 120 h self-study)
Credit points	6
Prerequisites for participation	none
Teaching goals	Understanding of the theoretical concepts of quantum optics, in particular the formulation of quantum systems in phase space. In addition the students learn to apply the theoretical concepts to modern experiments.
Course description	Quantization of the electromagnetic field Wigner function, Gaussian states Laser theory Optical components Interaction of light and matter Opto-mechanics
Assessment method	Written or oral exam, in addition possibly a presentation on a recent research paper.
Prerequisite for the award of credit points	Passed exam
Usability of the module	M-T1
Teaching style	Lecture with blackboard, exercises for self-study.
Literature	Schleich: Quantum Optics in Phase Space Loudon: The Quantum Theory of Light

Course title	Mathematics of quantum mechanics
Subtitle (if any)	
Abbreviation	M-WC5
Code	4PHY95021V, 4PHY95022V
Language	English
Regular cycle	annually at least one module in M-WC
Duration	1 semester
Responsible lecturer	Prof. Dr. O. Gühne
Teaching format	Lecture: 1 hours/week, tutorial: 1 hours/week, block course
Work load	90 h (30 h lectures and tutorials, 60 h self-study)
Credit points	3
Prerequisites for participation	none
Teaching goals	Understanding of the mathematical structure of quantum mechanics, especially the modern formulations for quantum channels and instruments.
Course description	Theory of Hilbert spaces, spectral theorems States and effects Observables and joint measureability Completely positive maps and channels POVMs and instruments Tensor products
Assessment method	Written or oral exam.
Prerequisite for the award of credit points	Passed exam
Usability of the module	M-T2
Teaching style	Lecture with blackboard, exercises for self-study.
Literature	Heinosaari, Ziman: The Mathematical Language of Quantum Theory Busch, Lahti, Pellonpää, Ylinen: Quantum Measurement

Course title	Quantum effects and quantum paradoxes
Subtitle (if any)	
Abbreviation	M-WC6
Code	4PHY95031V, 4PHY95032V
Language	English
Cycle	one course in M-WC annually
Duration	1 semester
Responsible lecturer	Prof. Dr. O. Gühne
Teaching format	Lecture: 2 hours/week, Tutorial: 2 hours/week
Work load	180 h (60 h lectures and tutorials, 120 h self-study)
Credit points	6
Prerequisites for participation	none
Teaching goals	The students know about surprising effects in quantum mechanics. Those effects can also have technological applications and the difference between classical and quantum mechanics is highlighted.
Course description	Interaction free measurements Zeno effect Multi-slit interference experiments Aharonov–Casher effect Superluminal tunneling Randomness in quantum measurements Wigner's friend The measurement problem and decoherence
Assessment method	Written or oral exam, in addition possibly a presentation on a recent research paper.
Prerequisite for the award of credit points	Passed exam
Usability of the module	M-T2
Teaching style	Lecture with blackboard, exercises for self-study.
Literature	Aharonov, Rohrlich: Quantum Paradoxes: Quantum Theory for the Perplexed Research papers

5.4 Experimental particle and astro-particle physics (M-WD)

Course title	Astroparticle physics
Subtitle (if any)	
Abbreviation	M-WD1
Code	4PHY91051V, 4PHY91052V
Language	German
Regular cycle	annually at least one course from M-WD
Duration	1 semester
Responsible lecturer	Prof. Dr. M. Risse
Teaching format	Lecture: 2 hours/week, tutorial: 2 hours/week
Work load	180 h (60 h lectures and tutorials, 120 h self-study)
Credit points	6
Prerequisites for participation	none
Teaching goals	The students learn the basic concepts and tools of astroparticle physics. In addition, they gain insights into recent research developments of astroparticle physics.
Course description	Cosmic rays: direct and indirect observations, acceleration and sources, propagation, air showers, experiments Current results: flux, composition, anisotropies, interaction processes, new physics Gamma-ray astronomy: gamma-ray bursts, TeV gamma astronomy Neutrino astronomy: sun, supernova 1987a, high-energy neutrinos Multimessenger astronomy (including gravitational waves)
Assessment method	Written or oral exam
Prerequisites for the award of credit points	Passed exam
Usability of the module	M-WD3
Teaching style	Lecture with blackboard, electronic media, exercises for self-study
Literature	Grupen: Astroteilchenphysik Klapdor-Kleingrothaus, Zuber: Teilchenastrophysik

Course title	Cosmology
Subtitle (if any)	
Abbreviation	M-WD2
Code	4PHY91061V, 4PHY91062V
Language	German
Regular cycle	annually at least one course from M-WD
Duration	1 semester
Responsible lecturer	Prof. Dr. M. Risse
Teaching format	Lecture: 2 hours/week, tutorial: 2 hours/week
Work load	180 h (60 h lectures and tutorials, 120 h self-study)
Credit points	6
Prerequisites for participation	none
Teaching goals	The students learn the basic concepts of cosmology. They learn about observational methods and mathematical descriptions of the universe. In addition, they gain insights into recent research developments of cosmology.
Course description	Observational methods World models, standard model of cosmology Determination of cosmological parameters Dark energy, dark matter Big bang, inflation Primordial nucleosynthesis Cosmic microwave background Structure formation
Assessment method	Written or oral exam
Prerequisites for the award of credit points	Passed exam
Usability of the module	
Teaching style	Lecture with blackboard, electronic media, exercises for self-study
Literature	Schneider: Einführung in die extragalaktische Astronomie und Kosmologie

Course title	Physics at the Pierre Auger Observatory
Subtitle (if any)	
Abbreviation	M-WD3
Code	4PHY91071V, 4PHY91072V
Language	German
Regular cycle	annually at least one course from M-WD
Duration	1 semester
Responsible lecturer	Prof. Dr. M. Risse
Teaching format	Lecture: 2 hours/week, tutorial: 2 hours/week
Work load	180 h (60 h lectures and tutorials, 120 h self-study)
Credit points	6
Prerequisites for participation	none
Teaching goals	The international Pierre Auger Observatory is the largest experiment for measuring cosmic rays at highest energies. The students learn key aspects of this research at the forefront of science. Topics include basic physical concepts, measurement principles, data analysis, current results and open questions.
Course description	Air showers Detectors of the Pierre Auger Observatory Cosmic rays Energy spectrum Mass composition Anisotropies Search for ultra-high energy photons and neutrinos Multimessenger astronomy (including gravitational waves) Search for violation of Lorentz invariance Hadronic interactions at highest energy
Assessment method	Written or oral exam
Prerequisites for the award of credit points	Passed exam
Usability of the module	M-E3
Teaching style	Lecture with blackboard, electronic media, exercises for self-study
Literature	Grupen: Astroteilchenphysik Klapdor-Kleingrothaus, Zuber: Teilchenastrophysik

Course title	Physics at the LHC
Subtitle (if any)	
Abbreviation	M-WD4
Code	4PHY91081V, 4PHY91082V
Language	English
Offered	annually min. one course from the elective subjects M-WD
Duration	1 semester
Responsible lecturer	Prof. Dr. I. Fleck
Teaching format	Lecture: 2 hours/week, tutorial: 2 hours/week
Work load	180 h (60 h lectures and tutorials, 120 h self-study)
Credit points	6
Prerequisites for participation	none
Teaching goals	The students learn about the physics processes in proton-proton collisions. They will be introduced to the current results of the LHC and thus to the research work in the experimental particle physics. The interface between theoretical and experimental particle physics will be demonstrated. The turorials include an introduction to the ROOT data analysis program, its application in simple practical problems, and exercises in experimental particle physics. Furthermore, original publications related to the topic will be discussed.
Course description	Hard scattering processes Hadronization Jet algorithms Proton structure functions Vector boson production Physics of the Top Quark Physics of the Higgs boson
Assessment method	Written or oral exam or a presentation on a recent research paper.
Prerequisite for the award of credit points	Passed exam
Usability of the module	M-WE3
Teaching style	Lecture with blackboard/electronic media, exercises for self-study, computing exercises.
Literature	Thomson: Modern Particle Physics Berger: Elementarteilchenphysik

5.5 Theoretical Particle physics: Phenomenology of the Standard Model (M-WE)

Course title	Flavour Physics
Subtitle (if any)	Flavour Physics in Experiment and Theory
Abbreviation	M-WE1
LSF Code	4PHY94011V, 4PHY94012V
Language	English
Regular cycle	at least one course in M-WE per year
Duration	1 semester
Responsible lecturer(s)	Prof. Dr. T. Mannel, Prof. Dr. B Spaan (TU Dortmund)
Teaching format	Lecture 2 hours/week, tutorial 2 hours/week
Work load	180 h (60 h lectures and totorials, 120 h self-study)
Credit points	6
Prerequisites for participation	M-T3
Teaching goals	The goal of the lecture is to provide an overview over the modern methods of flavour physics. On the theoretical side this includes the basics of the flavour sector of the standard model, on the experimental side the basic techniques of the currently running as well as of the planned experiments in flavour physics are described.
Course description	Introduction into flavour physics Flavour in the standard model The CKM Matrix Measurements of CKM matrix elements Physics of the Top quark Violation of CP Symmetry Effective interaction for weak decays Rare decays in experiment and theory Flavour physics of leptons The modue is designed as an integrated course between experiment and theory. The theoretical lectures are taught by a theorist from Siegen, the experimental part is taught by an experimental colleague from Dortmund.
Assessment method	Written or oral exam
Prerequisite for the award of credit points	Passed exam
Usability of the module	M-WE2, M-WF1, M-WF2
Teaching style	Lecture with blackboard and beamer presentation, problem sheets
Literature	Bevan et al: The Physics of the B Factories, Eur. Phys. J. C74 (2014) 3026

Course title	Physics of Hadrons
Subtitle	Hadrons in Quantum Chromodynamics
Abbreviation	M-WE2
Code	4PHY94021V, 4PHY94022V
Language	English
Offered	annually at least one course from the module M-WE
Duration	1 Semester
Responsible lecturer	Prof. Dr. T. Feldmann
Duration	Lecture 2 hours/week; tutorium, 2 hours/week
Workload	180 h (60 h lectures and tutorials, 120 h self-study)
Credit points	6
Prerequisits for participation	M-T3, M-T4
Teaching goals and objectives	The students familiarize themselves with the structure, nomenclature and quantum numbers of mesons and baryons in the quark model, They can describe decays and scattering processes with hadrons within the parton picture, reducing them to the relevant hadronic quantities. The students learn approximate symmetries and the resulting theoretical methods, allowing them to obtain quantitative estimates of elementary hadronic observables.
Course description	Quark structure and the spectroscopy of hadrons Isospin, hypercharge, $SU(3)$ flavour symmetry Symmetries of hadrons with heavy quarks Phenomenology of hadronic decays and scattering processes Hadronic structure functions Decay constants and form factors Chiral perturbation theory Effective theory of heavy quarks Operator product expansion, quark and gluon condensates Analyticity, unitarity and dispersion relations QCD sum rules and light-cone sum rules
Assessment method	written or oral exam
Prerequisite for the award of credit points	Passed exam
Usability of the module	MWE-1, MWE-3, MWF-2
Teaching style	Lecture with blackboard, exercises for self-study.
Literature	Nachtmann: Elementary Particle Physics Halzen, Martin: Dynamics of the Standard Model Donoghue, Golowich, Goldstein: Dynamics of the Standard Model

Course title	Collider physics
Subtitle (if any)	
Abbreviation	M-WE3
Code	4PHY94031V, 4PHY94032V
Language	English
Regular cycle	annually at least one course from M-WE
Duration	1 semester
Responsible lecturer	Prof. Dr. G. Bell
Teaching format	Lecture: 3 hours/week, tutorial: 1 hour/week
Work load	180 h (60 h lectures and tutorials, 120 h self-study)
Credit points	6
Prerequisites for participation	M-T3, M-T4
Teaching goals	The students learn the basic concepts of theoretical collider physics. In particular, they understand how to interpret ultraviolet and infrared divergences that arise in perturbative QCD calculations, and they learn how to define jets in a lepton and a hadron collider environment. Elementary scattering processes at the Large Hadron Collider are also discussed.
Course description	Basic principles of Quantum Chromodynamics, renormalisation e^+e^- scattering, infrared divergences Jet algorithms, event-shape variables Operator product expansion Deep-inelastic scattering, parton model Parton distribution functions, DGLAP equations Proton-proton scattering, Drell-Yan production Soft-Collinear Effective Theory
Assessment method	Written or oral exam
Prerequisite for the award of credit points	Passed exam
Usability of the module	M-WD4, M-WE4, M-WF2, M-WF3
Teaching style	Lecture with blackboard, exercises for self-study.
Literature	Peskin, Schröder: Introduction to Quantum Field Theory Schwartz: Quantum Field Theory and the Standard Model Ellis, Stirling, Webber: QCD and collider physics Dissertori, Knowles, Schmelling: QCD Becher, Broggio, Ferroglia: Introduction to Soft-Collinear Effective Theory

Course title	Higgs Physics
Subtitle (if any)	
Abbreviation	M-WE4
Code	4PHY94041V, 4PHY94042V
Language	English
Regular cycle	jährlich mind. eine Veranstaltung aus Wahlbereich M-WE
Duration	1 semester
Responsible lecturer	Prof. Dr. W. Kilian
Teaching format	Lecture: 2 hours/week, tutorial: 2 hours/week
Work load	180 h (60 h lectures and tutorials, 120 h self-study)
Credit points	6
Prerequisites for participation	M-T3
Teaching goals	The students acquire knowledge about phenomenological aspects and theoretical concepts of Higgs physics. They learn to assess the motivation and possible scenarios for new phenomena in the context of the current state of particle physics.
Inhalt	Spontaneous symmetry breaking in quantum field theory Higgs mechanism in the Standard Model of particle physics Decays of the Higgs boson Production of the Higgs boson at e^+e^- and pp colliders Radiative corrections to Higgs processes Anomalous Higgs couplings and effective theory Extended Higgs models
Assessment method	Written or oral exam
Prerequisite for the award of credit points	Passed exam
Usability of the module	M-WE3, M-WF1, M-WF2
Teaching style	Lecture with blackboard, exercises for self-study.
Literature	Gunion, Dawson, Haber, Kane: The Higgs Hunter's Guide LHC Higgs Cross Section WG: Handbook of LHC Higgs Cross Sections

5.6 Theoretical particle physics: Advanced methods (M-WF)

Course title	Physics beyond the Standard Model
Subtitle (if any)	
Abbreviation	M-WF1
Code	4PHY94051V, 4PHY94052V
Language	English
Regular cycle	aperiodic, one course from M-WF each year
Duration	1 semester
Responsible lecturer	Prof. Dr. T. Feldmann
Teaching format	Lecture 2 hours/week, tutorial 2 hours/week
Work load	180 h (60 h lectures and tutorials, 120 h self-study)
Credit points	6
Prerequisites for participation	M-T3, M-T4
Teaching goals	The students are aware of the shortcomings of the Standard Model (SM) of particle physics, which motivates the search for physics beyond the SM (BSM) at present collider experiments. The students are familiar with the theoretical concepts that are used to construct BSM models and know which observables can be studied to confirm or exclude different approaches.
Course description	Open questions in the Standard Model Supersymmetry and Poincaré group Construction and phenomenology of the MSSM Grand Unified Theories: SU(5), SO(10), Pati-Salam Little-Higgs models and compositeness Models with extra dimensions
Assessment method	Written or oral exam
Prerequisite for the award of credit points	Passed exam
Usability of the module	MWE-1, MWE-4
Teaching style	Lecture with blackboard, exercises for self-study.
Literature	Weinberg: QFT III Kane: Perspectives on SUSY Martin: hep-ph/9709356 Georgi: Lie Algebras in Particle Physics Slansky: Phys.Rept. 79, 1 Perelstein: hep-ph/0512128 Schmaltz,Tucker-Smith: hep-ph/0502182

Course title	Effektive Field Theories and Renormalisation-Group
Subtitle (if any)	
Abbreviation	M-WF2
Code	4PHY94061V, 4PHY94062V
Language	English
Regular cycle	at least one course annually from the set of electives M-WF
Duration	1 semester
Responsible lecturer	Prof. Dr. T. Mannel
Teaching format	Lecture: 2 hours/week, tutorial: 2 hours/week
work load	180 h (60 h lectures and tutorials, 120 h self-study)
Credit points	6
Prerequisites for participation	M-T3, M-T4
Teaching goals	Students learn the underlying principles of effective field theories in general and apply them to specific examples. The main teaching goals are a deep appreciation of the renormalisation-group in quantum field theory, and a skilled application of its methods in various areas of quantum field theory.
Course description	Pathintegrals and generating functionals, effective actions and effective Lagrangians, dimensional regularisation, method of regions, renormalisation-group equations, running couplings, operator mixing under renormalisation, Wilson coefficients, resummation of large logarithms within perturbation theory. Introductions to Fermi-theory of weak interactions, Chiral Perturbation Theory, Heavy-Quark Expansion, Heavy-Quark Effective Theory, and Soft-Collinear Effective Theory.
Assessment method	Written or oral exam, or possibly a take-home exam.
Requirement for the award of credit points	Passed exam
Usability of the module	M-WE1, M-WE3, M-WF1, M-WF3
Teaching style	Lectures on blackboard, exercises for self-study
Literature	Becher: Introduction to Soft-Collinear Effective Theory Manohar, Wise: Heavy Quark Physics Petrov: Effective Field Theories Schwartz: Quantum Field Thoery and the Standard Model

Course title	Tools for the calculation of loop diagrams
Subtitle (if any)	
Abbreviation	M-WF3
Code	4PHY94071V, 4PHY94072V
Language	English
Regular cycle	At least one course per year from section M-WF
Duration	1 semester
Responsible lecturer	PD Dr. T. Huber
Teaching format	Lecture: 3 hours/week, Tutorial: 1 hour/week
Work load	180 h (60 h lectures and tutorials, 120 h self-study)
Credit points	6
Prerequisites for participation	M-T3, M-T4
Teaching goals	The computation of radiative corrections in quantum field theory requires the evaluation of so-called loop integrals. Based on the method of dimensional regularisation the students become familiar with analytical and numerical techniques to compute such integrals, including the connection to scattering and decay processes at colliders. In the tutorials the students deepen the lecture material and learn to use existing programs for evaluating loop integrals by means of a computer.
Course description	Properties of loop integrals in dimensional regularisation Feynman and Schwinger parameters Sector decomposition Mellin-Barnes representations Integration-by-parts relations, reduction to master integrals Differential equations Asymptotic expansions
Assessment method	Written or oral exam
Prerequisite for the award of credit points	Passed exam
Usability of the module	M-WE3, M-WE4, M-WF2
Teaching style	Lecture with blackboard and PC presentations, exercises for self-study.
Literature	Smirnov: Analytic Tools for Feynman Integrals

Course title	Special Topics in Quantum Field Theory
Subtitle (if any)	
Abbreviation	M-WF4
LSF Code	4PHY94081V, 4PHY94082V
Language	English
Regular cycle	at least one course in M-WE per year
Duration	1 semester
Responsible lecturer(s)	Prof. Dr. T. Mannel
Teaching format	Lecture 1 hours/week, tutorial 1 hours/week
Work load	90 h (30 h lectures and totorials, 60 h self-study)
Credit points	3
Prerequisites for participation	M-T3, M-T4
Teaching goals	Starting form a basic knowledge of quantum field theory some special proporties of quantum field theories are explained, which are of relevance in different fields of physics. This includes renormalization iand spontaneous symmetry breaking. The goal is to introduce the students to apply advanced methods of quantum field theory.
Course description	Advanced functional methods in quantum field theory represnetations of symmetries in quantum field theory Spontaneous symmetry breaking and the Higgs mechanism Anomalous symmetries Mathematical of gauge theories Quantization of gauge theories Nonperturbative aspects of quantum field theory Infrared problems in quantum field theory
Assessment method	Written or oral exam
Prerequisite for the award of credit points	Passed exam
Usability of the module	
Teaching style	Lecture with blackboard an beamer presentation, problem sheets
Literature	Weinberg: The Quantum Theory of Fields, Vol. 1,2.

6 Module descriptions: Mandatory modules

6.1 Master lab course (M-P)

Course title	Master lab course
Subtitle (if any)	
Abbreviation	M-P
Code	4PHY20054V
Language	German / English
Regular cycle	every winter semester
Duration	1 semester
Responsible lecturer	Prof. Dr. I. Fleck
Teaching format	Lab 4 hours/week
Work load	270 h (60 h lectures and tutorials, 210 h self-study)
Credit points	9
Prerequisites for participation	none
Teaching goals	The students extend their practical skills by means of experiments they carry out themselves and they are introduced to the independent scientific work. The students learn how to use analysis programs and deepen their knowledge of error calculation through the quantitative evaluation of the experiments. A critical evaluation of the design and performance of the experiment as well as of the results is part of the report.
Course description	A selection of experiments on the following topics: Life time π-μ-K β-spectroscopy Nuclear life time Dynamic light scattering X-ray fluorescence X-Ray reflectometry Laser Spectroscopy Scanning Tunneling Micoscopy Surface Plasmon Polariton sensing Fluorescence Correlation Spectroscopy Top quark physics Characteristics of different physical systems and methods General Issues in Experimental Physics
Assessment method	The experiments performed and the reports are evaluated. The requirements for the reports will be announced at the beginning of the course.
Prerequisite for the award of credit points	Accepted experiment reports
Usability of the module	
Teaching style	Manual for performing experiments independently, electronic media.
Literature	Bergmann, Schaefer: Experimentalphysik Demtröder: Experimentalphysik Kittel: Festkörperphysik Als-Nielsen, McMorrow: Elements of Modern X-ray Physics

6.2 Master seminar (M-S)

Course title	Master seminar
Subtitle (if any)	
Abbreviation	M-S
Code	4PHY20203V
Language	German / English
Regular cycle	annually at least one corse
Duration	1 semester
Responsible lecturer	Lecturers of the physics department
Teaching format	Seminar 2 hours/week
Work load	180 h (30 h seminar, 150 h self-study)
Credit points	6
Prerequisites for participation	none
Teaching goals	Students learn how to prepare a seminar presentation on a selected topic using specialized literature and how to use advanced presentation techniques.
Course description	Questions from the research areas of the department: Solid state physics and x-ray optics Experimental quantum optics and nano-optics Experimental particle and astroparticle physics Theoretical quantum optics Theoretical particle physics
Assessment method	Presentation
Prerequisite for the award of credit points	Presentation rated at least with the grade ”sufficient”
Usability of the module	
Teaching style	Presentation, electronic media
Literature	Will be announced during the course.

6.3 Research phase (M-A)

Course title	Research preparation project
Subtitle (if any)	
Abbreviation	M-AV
Code	
Language	German / English
Duration	1/2 semester
Responsible lecturer	Lecturer of Physics
Teaching format	Full-day supervised research work
Work load	450 h
Credit points	15
Prerequisites for participation	none
Teaching goals	The research preparation project deals with preparatory tasks. In this way, the students should demonstrate that they have acquired the specialized knowledge and methods to such an extent that they can successfully apply them to questions from the field from which the topic of the Master's thesis is to originate.
Course description	Topic depending on the orientation of the thesis
Assessment method	Oral proof of preparation
Teaching style	Instructed self-study
Literature	Depending on the chosen research area

Course title	Thesis training project
Subtitle (if any)	
Abbreviation	M-AE
Code	
Language	German / English
Duration	1/2 semester
Responsible lecturer	Lecturer of Physics
Teaching format	Full-day supervised training
Work load	450 h
Credit points	15
Prerequisites for participation	M-AV
Teaching goals	The thesis training project serves the purpose of in-depth study and the acquisition of knowledge of the scientific literature and the current status of the special field from which the topic of the Master's thesis is to originate. Special experimental measurement methods and evaluation methods or theoretical models and calculation methods are to be developed and reproduced using simple examples.
Course description	Topic depending on the orientation of the thesis
Assessment method	Oral proof of training
Teaching style	Instructed self-study
Literature	Depending on the chosen research area

Course title	Master thesis
Subtitle (if any)	
Abbreviation	M-A
Language	German / English
Duration	1 semester
Responsible lecturer	Lecturer of Physics
Teaching format	Full-day supervised research work
Work load	900 h
Credit points	30
Prerequisites for participation	M-AV, M-AE
Teaching goals	Under guidance, the students carry out scientific work at the forefront of research. They learn techniques for carrying out this research. The preparation of the final thesis trains the ability to process one's own research work in a way that others can understand.
Course description	Topic depending on the orientation of the thesis
Assessment method	Graded written master thesis
Teaching style	Instructed research work
Literature	Depending on the chosen research area

7 Contact persons and further information

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Note

This document is a non-committal translation of the German version.