Module handbook

for the study program

Physics, Master of Science

of the TU Dortmund University

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Preface

Numbering Scheme

The modules of the subject physics are provided here with a number of the form **PHYklmn:**

- **k is** the number of the semester in which this module can normally be started. The semesters of the Bachelor's and Master's program are numbered consecutively, i.e. k=1,... ,6 for the bachelor program and k=7,...,10 for the master program,
- **l** the type of course:
  l=1: Theoretical and experimental physics, e.g. integrated course;
  l=2: Experimental physics;
  l=3: Theoretical physics;
  l=4: Laboratory course,
- **mn** an ordinal number.

The import modules from mathematics, chemistry and computer science used in the bachelor's program are listed in the form published by the offering faculties. Therefore, they are also not numbered according to the scheme described above and the descriptions are designed differently.

General remarks

The modules of the elective area or the general area of specialization in the Bachelor's degree program and in the Master's degree program can be found in the module catalogs of the offering faculties. These are defined in more detail by the respective examination regulations. The selection of the possible modules is made in coordination between the participating subjects or faculties. A rigid catalog does not make sense in the interest of flexibility and adaptation to new developments in science and in the professional field. As an indication of possible combinations of modules in these areas, examples of proven combinations of courses are published on the Internet.

The list of elective modules for the elective area or the physics specialization area is also not to be regarded as exclusive or rigid. Here, too, it must be possible to take new developments into account; furthermore, it should also be possible to use courses taught by guest lecturers as well as courses taught by external lecturers habilitated at the faculty (ISAS, DESY, etc.) as well as other courses in these areas that do not take place on a regular basis.

No fixed modules or module combinations have been prescribed for the elective area or the physics specialization area in order to allow students to set their own individual focus, especially in the master's program. This focus is set in coordination with the lecturers, the student advisor and the examination board. It has been shown that a canon of sensible standard combinations emerges, to which the students orient themselves.

Many of the elective modules are therefore deliberately kept small (3CP) to allow students, in consultation with the lecturers, to optimally adapt to individual specialization preferences. For example, module 825 (Fundamentals of Detector Physics, 3CP) together with 823 (Astroparticle Physics, 6CP) and 7210 (Seminar: Particle and Astroparticle Physics, 3CP) could be a useful physics specialization in view of a master thesis in astroparticle physics. However, the same module 825 can also be used with 622 (Introduction to Medical Physics, 8 CP) and Radiation Therapy and Dosimetry (from the Medical Physics course) for a specialization in medical physics, or, combined still differently, in traditional particle physics at accelerators. In the interest of clarity, an exhaustive list of *all* possible combinations does not seem useful.

The module "Hauptseminar in Physics" according to §17 of the Master's Examination Regulations is not further specified in terms of subject matter, since all working groups of the faculty regularly offer seminars at the corresponding level. Some of them are explicitly described in the module catalog to indicate that they are well suited for an area of specialization in combination with other modules; an example is for instance PHY726. Of course, a seminar used for an area of specialization cannot be used again as a physics major seminar. Credit points for seminars are only awarded for regular active participation in the seminar discussions; in addition, an individual contribution must be presented.

As is common in most physics departments and faculties, required courses and major electives rotate among instructors; therefore, module descriptions do not include instructor names.

For the majority of the modules in physics, the literature used is given in the module descriptions. Further literature will be announced at the beginning of each module by the current lecturers, on request also in advance.

Many modules from the Bachelor's or Master's program in Medical Physics can also be used in the Bachelor's and Master's programs in Physics, for example the modules Medical Physics I and II and other modules whose contents are not largely covered by compulsory, elective or optional modules of the Bachelor's and Master's programs in Physics. These modules are described in the corresponding module manual of the Master's program in Medical Physics.

Work load

The work load of one credit point corresponds to 30 hours of work. The work load quoted in the description of the modules below 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 §9 of the Master's Examination Regulation.

Teaching methods

The teaching methods used depend on the type of course:

- “Lecture” (L)for lecture-type courses and seminars given by invited speakers
- “Problem-based learning” (T) for tutorials/exercise sessions, e.g. in theoretical physics
- “Seminar” (S) for presentations prepared by students
- “Directed discussion” for an in-class discussion of the presented material organized by the teacher
- “Laboratory method” (P) 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.

Sorted by Module Number

Module No.	Module title	Module Type	Kind of module	CP	Responsibility	Turnus	Block course	Course Work
PHY412a	Basic Concepts of Physics	L	elective	6	Rhode	SS		
PHY412b	Basic Concepts of Physics	L	elective	5	Rhode	SS		
PHY421	Instruments of Modern Physics	L+T	elective	5	Khan	as needed		
PHY515	Physics of Sailing	S	elective	3	Khan, Päs	WS		
PHY523a	Statistical Methods of Data Analysis / SMD A	L+T	elective	5	Rhode	SS		yes
PHY523b	Statistical Methods of Data Analysis / SMD B	L+T	elective	5	Rhode	WS		yes
PHY524	Physics and Technology of Arms Limitation Treaty Verification	L	elective	3	Altmann	WS		
PHY525	Statistical Methods of Data Analysis 2	L	elective	3	Rhode	WS	yes	yes
PHY528	Nuclear Energy and Other Energy Issues	S	elective	3	Albrecht	WS		
PHY5210L	Magnetism	L	elective	6	Cinchetti	WS/SS		
PHY5210S	Magnetism	S	elective	3	Cinchetti	WS/SS		
PHY5211	Materials for Nanoelectronics and High-Speed Quantum Electronic Devices	L+S	elective	5	Vitusevich	WS		
PHY5214	Physics on ultrashort time scales	S	elective	3	Helml/Khan	WS/SS		
PHY5216	Photovoltaics	S	elective	3	Dean of the Department of Physics	as needed in WS		
PHY5218	Einführung in die Quantentechnologien	L	elective	3	Dean of the Department of Physics	WS		
PHY533	Group Theory in Physics I	L+T	elective	6	Dean of the Department of Physics	annual		yes
PHY534	Introduction to Quantum Field Theory of Elementary Particles	L	elective	3	Blümlein	as needed	yes	
PHY535	Cosmology, Quantum Cosmology, Gravitational Waves	L+T	elective	9	Päs	as needed		yes
PHY537	Group Theory in Physics II	L+T	elective	5	Löw	as needed		yes

PHY538	Group Theory in Solid State Physics	L+T	elective	6	Bünemann	as needed		yes
PHY621	Electronics	L+T	elective	8	Dean of the Department of Physics	SS		yes
PHY622	Medical Physics I	L+T	elective	8	Dean of the Department of Physics	SS		yes
PHY623	Magnetic Resonance	L(+T)	elective	5	Dean of the Department of Physics	SS		
PHY626	Machine Learning for Physicists	L+T	elective	4	Dean of the Department of Physics	SS		yes
PHY627	Current Topics and Techniques in Surface Physics	S	elective	3	Westphal	as needed		
PHY628	Advanced Nonlinear Spectroscopic Methods in Solid State Physics	L	elective	3	Bossini/Yakovlev	SS		
PHY629	Applied Dosimetry	S	elective	3	Kröninger	annually in WS		
PHY6210	Methods of Clinical Research	L	elective	5	Weinreich	as needed in SS		
PHY6211	Applications of Machine Learning in Medical Physics	S	elective	3	Dean of the Department of Physics	WS		
PHY6212	Superconductivity	L	elective	3	Z. Wang	SS		
PHY6214	Cold atoms and molecules	L+T	elective	6	Narevicius/ Weitenberg	SS		
BP12	Physics of Life	L+T	elective	6	Schneider	WS		
PHY631	Advanced Quantum Mechanics	L+T	elective	6	Dean of the Department of Physics	SS		yes
PHY632	Computational Physics	L+T	elective	9	Dean of the Department of Physics	SS		yes
PHY633	Theory of Soft and Biological Matter	L+T	elective	6	Kierfeld	SS		yes

PHY634	General Relativity	L+T	elective	6	Dean of the Department of Physics	SS		yes
PHY635	Advanced Solid State Physics I: Semiconductors and Light-Matter Interaction	L	elective	6	Dean of the Department of Physics	SS		
PHY712	Accelerator Physics I	L+T	elective	6	Dean of the Department of Physics	WS		yes
PHY7238	Ethics of the Natural Sciences	S	elective	3	Rhode	WS		
PHY713	Soft Matter and Biophysics: Experiment and Theory	S	elective	3	Kierfeld	WS		
PHY714	Molecular Simulation of Soft Matter and Biological Materials	L+T	elective	6	Risselada	WS		
PHY722	Current Problems in the Field of Synchrotron Radiation Utilization and Tunneling Microscopy	S	elective	3	Dean of the Department of Physics	WS/SS		
PHY723	Key Experiments in Particle Physics	S	elective	4	Dean of the Department of Physics	annual		
PHY724	Measurement Methods in Surface Physics	L+T	elective	6	Westphal	WS		
PHY726	Accelerator Physics and Synchrotron Radiation: Applications in Solid State Physics	S	elective	3	Dean of the Department of Physics	WS/SS		
PHY727	Atomically Resolved Surface and Interface Analysis	L	elective	3	Dean of the Department of Physics	SS		
PHY728	Solid State Spectroscopy	S	elective	3	Dean of the Department of Physics	WS/SS		
PHY729	Lasers - Types and Applications	S	elective	3	Dean of the Department of Physics	annual		
PHY7210	Particle and Astroparticle Physics	S	elective	3	Dean of the Department of Physics	WS/SS		
PHY7211	Neutrino and Gamma Astronomy	S	elective	3	Rhode	WS/SS		

PHY7212	Particle Physical Aspects of Cosmic Rays	S	elective	3	Rhode	as needed		
PHY7213	Modern Optics	S	elective	3	Dean of the Department of Physics	SS		
PHY7214	Quantum Optics	L	elective	3	Dean of the Department of Physics	WS		
PHY7215	Reading course on particle physics	S	elective	3	Dean of the Department of Physics	WS		
PHY7217	Radio Astronomy	S	elective	3	Rhode	WS		
PHY7218	Cosmic Rays	S	elective	3	Rhode	as needed		
PHY7219a	Physical-Chemical Analytics 1a, Applied Spectrometry	L	elective	3	Franzke	as needed		
PHY7220a	Physical-Chemical Analytics 2a, Applied Plasma Physics	L	elective	3	Franzke	2-year		
PHY7221a	Physical-Chemical Analytics 3a, Applied Laser Spectrometry	L	elective	3	Franzke	2-year		
PHY7219b	Physical-Chemical Analytics 1b, Applied Spectrometry	L+P	elective	5	Franzke	as needed		
PHY7220b	Physical-Chemical Analytics 2b, Applied Plasma Physics	L+P	elective	5	Franzke	2-year		
PHY7222a	Magnetism II	L	elective	3	Cinchetti	as needed		
PHY72222b	Magnetism II	S	elective	3	Cinchetti	as needed		
PHY7224	Information Technology of the Future	S	elective	3	Cinchetti	as needed		
PHY7225	Tandem Projects in Particle Physics	PW+L	elective	6	Kröninger	annual		
PHY7226	Applied Physics in Clinical Medicine	S	elective	3	Schilling	WS		
PHY7227	The Search for New Particles, Dark Matter & Co.	S	elective	3	Kröninger	WS		
PHY7228	Superconducting Technology applied to particle accelerators	S	elective	3	Velez Saiz	WS	yes	
PHY7229	Terahertz Dynamics of Condensed Matter	S	elective	3	Lange/Z. Wang	WS/SS		
PHY7230	Quantum Technologies	S	elective	3	Aßmann	as needed in WS and SS		

PHY7231	Dynamics of Open Quantum Systems	L+T	elective	5	Aßmann	as needed in WS and SS		
PHY7232	Physics of the Top Quark and the Higgs Boson	L+T	elective	6	Dean of the Department of Physics	as needed in SS		yes
PHY7233	Practical Aspects of Instrumentation	L(+T)(+S)	elective	3 or 6 or 9	Dean of the Department of Physics	WS/SS		
PHY7234	Laboratory of Condensed Matter Physics: Time-Resolved Photoemission	L+T	elective	6	Zamborlini	as needed		
PHY7235	Advanced Solid State Physics II – Magnetism and Superconductivity	L	elective	6	Dean of the Department of Physics	WS		
PHY7236	Ultrafast Spectroscopic Methods in Solid State Physics	L	elective	3	Kovalev/Z. Wang	SS		
PHY7237	Condensed matter physics: Time-domain Terahertz spectroscopy	L+T	elective	6	Ghalgaoui/Z. Wang	as needed		
PHY7238	Quantum simulation with cold atoms and molecules	S	elective	3	Narevicius/ Weitenberg	WS		
PHY7239	Particle Physics meets Astroparticle Physics	S	elective	3	Albrecht	as needed		
PHY731	Introduction to Theoretical Elementary Particle Physics	L+T	specialization or elective	12	Dean of the Department of Physics	annually in WS		yes
PHY732	Introduction to Theoretical Solid State Physics	L+T	specialization or elective	12	Dean of the Department of Physics	WS		yes
PHY733	Quantum Field Theory	L+T	elective	6	Dean of the Department of Physics	annual		yes
PHY734	Theory of Strongly Correlated Systems and Quantum Information	S	elective	3	Dean of the Department of Physics	WS/SS		
PHY735	Introduction to the Renormalization Group	L	elective	4	Anders	as needed in WS		

PHY736	Physics Beyond the Standard Model (BSM Seminar)	S	elective	3	Dean of the Department of Physics	WS/SS		
PHY737	Theoretical Problems of Condensed Matter	S	elective	3	Dean of the Department of Physics	SS/WS		
PHY738	Hadrons in Quantum Chromodynamics	L	elective	4	Khodjamirian/Hiller	as needed in WS		
PHY739	Differential Geometry / General Relativity	S	elective	5	Löw/Schwachhöfer	irregular		
PHY7310	Big Questions	S	elective	3	Päs	WS		
PHY7311	Neutrinos and Cosmology	S	elective	3	Päs	WS		
PHY7312	Theory of Magnetism in Solids	L+T	elective	6	Bünemann	irregular		
PHY7313	Theory of Soft and Biological Matter	L+T	elective	5	Kierfeld	WS		
PHY7314	Quantum Theory of Semiconductors	L	elective	3	Reiter	as needed		
PHY7315	Ask me anything: Quantum Dots	S	elective	3	Reiter	as needed		
PHY7316	Advanced Topics in Quantum Field Theory	L+T/S	elective	6	Stamou	as needed		
PHY7317	From Standard Model to BSM Physics	L	elective	3	Hiller	SS		
PHY7318	Quantum Information (From Qubits to Black Holes)	L	elective	3	Päs	as needed		
PHY7319	Modern Quantum Computing and Quantum Simulation	L+T	elective	6	Fauseweh	SS		
PHY742	Advanced Laboratory Course for Master Students I	P	mandatory	6	Dean of the Department of Physics	WS		yes
KM09/APM11	Applied Proton Therapy	P	elective	6	Lühr	SS		
PHY811	Flavor Physics in Experiment and Theory	L+T	elective	6	Mannel/Albrecht	as needed in SS		yes
PHY812	Accelerator Physics II	L+T+S	elective	6	Dean of the Department of Physics	SS		yes
PHY822	Experimental aspects of particle physics	L+T	elective	6	Dean of the Department of Physics	SS		yes
PHY823	Astroparticle Physics	L+T	elective	6	Rhode	SS		

PHY823.2	Astroparticle Physics II	L+T	elective	3	Rhode	WS		
PHY825	Fundamentals of Detector Physics	L	elective	3	Dean of the Department of Physics	annually in SS		
PHY826	Detector systems in particle and medical physics	S	elective	3	Dean of the Department of Physics	WS		
PHY827	False Discoveries in Particle Physics	S	elective	3	Dean of the Department of Physics	as needed		
PHY829	Structural Analysis with X-rays	L+T	elective	5	Sternemann/Paulus	SS	yes	
PHY8210	External School in Particle Physics	L	elective	1	Dean of the Department of Physics	irregular	yes	
PHY8211a	Applications of Synchrotron Radiation	L	elective	3	Zamborlini	SS		
PHY8211b	Applications of Synchrotron Radiation	S	elective	3	Zamborlini	SS		
PHY8212	Light-Matter Interaction	L+T	elective	6	Lange	WS		
PHY8213	Light-Matter Interaction	S	elective	3	Lange	WS		
PHY8214	Introduction to the clinical application of magnetic resonance imaging	L+T+S+P	elective	6	Salehi Ravesh	annual		
PHY8215	Quantitative Magnetresonanztomographie: von Spinanregung zum Bild	S	elective	6	Salehi Ravesh	annual		yes
PHY8216	Ultrafast spintronics and light driven magnetisation dynamics	S	elective	3	Kovalev/Z. Wang	SS		
PHY831	Many-Particle Solid-State Theory	L+T	elective	8	Dean of the Department of Physics	as needed		
PHY832a	Cosmology	L	elective	3	Dean of the Department of Physics	as needed		
PHY832b	Cosmology	L+T	elective	6	Päs	as needed		
PHY833	Flavor Physics	L+T	elective	6	Dean of the Department of Physics	annual		yes
PHY834	Introduction to Renormalization of Quantum Field Theories	L	elective	2	Blümlein	as needed	yes	

PHY835	Introduction to Grand Unified Theories	L	elective	2	Blümlein	as needed	yes	
PHY836	Introduction to Group Theory and Lie Algebras	L	elective	2	Blümlein	SS	yes	
PHY837	Calculation Methods for Feynman Diagrams	L+T	elective	2	Blümlein	as needed	yes	
PHY838	Theory of Soft and Biological Matter II	L+T	elective	5	Kierfeld	as needed		
PHY839	Advanced Methods in Theoretical High-Energy Physics	L(+T)	elective	2/3	Stamou	WS/SS	yes	
PHY8310	Renormalization in Theoretical High-Energy Physics	L+T	elective	3	Hiller	as needed		
PHY8311	Seminar: Modern Quantum Computing and Quantum Simulation	S	elective	3	Fauseweh	as needed		
PHY842	Advanced Laboratory Course II: Solid State Physics	P	elective	6	Dean of the Department of Physics	SS		yes
PHY843	Advanced Laboratory Course II: Particle Physics	P	elective	6	Dean of the Department of Physics	SS		yes
PHY844	Advanced Laboratory Course II: Theoretical Course	P	elective	6	Kierfeld	annual		yes
PHY845	Advanced Laboratory Course II: Electronics	P	elective	6	Dean of the Department of Physics	SS		yes
PHY846	Condensed Matter Theory Laboratory Course	S	elective	3	Kierfeld	annual		yes
PHY911	Research Internship	Research internship	mandatory	15	Dean of the Department of Physics	WS/SS		
PHY912	Methods and Project Planning	L+S	mandatory	15	Dean of the Department of Physics	WS/SS		
PHY921	Particle physics meets industry	S	elective	3	Kröninger	WS/SS		yes
PHY1011	Master’s thesis	Supervised research	mandatory	30	Dean of the Department of Physics	WS/SS		
	English for Physics C1	T	elective	6	zhb	WS		
KM10	Moderne Strahlentherapie	L+P	elective	3	Hammi	WS		yes
	Thin film growth: From low-dimenaional physics to industrial applications	L+T	elective	6	Bedoya-Pinto	WS		

Sorted by Module Type

Module No.	Module title	Module Type	Kind of module	CP	Responsibility	Turnus	Block course	Course Credits
PHY412a	Basic Concepts of Physics	L	elective	6	Rhode	SS		
PHY412b	Basic Concepts of Physics	L	elective	5	Rhode	SS		
PHY524	Physics and Technology of Arms Limitation Treaty Verification	L	elective	3	Altmann	WS		
PHY525	Statistical Methods of Data Analysis 2	L	elective	3	Rhode	WS	yes	yes
PHY5218	Einführung in die Quantentechnologien	L	elective	3	Dean of the Department of Physics	WS		
PHY5210L	Magnetism	L	elective	6	Cinchetti	WS/SS		
PHY534	Introduction to Quantum Field Theory of Elementary Particles	L	elective	3	Blümlein	as needed	yes	
PHY628	Advanced Nonlinear Spectroscopic Methods in Solid State Physics	L	elective	3	Bossini/Yakovlev	SS		
PHY6210	Methods of Clinical Research	L	elective	5	Weinreich	as needed in SS		
PHY6212	Superconductivity	L	elective	3	Z. Wang	SS		
PHY6214	Cold atoms and molecules	L+T	elective	6	Narevicius/ Weitenberg	SS		
PHY6215	Quantum Technologies with Atoms and Photons	S	elective	3	Narevicius/ Weitenberg	SS		
PHY635	Advanced Solid State Physics I: Semiconductors and Light-Matter Interaction	L	elective	6	Dean of the Department of Physics	SS		
PHY727	Atomically Resolved Surface and Interface Analysis	L	elective	3	Dean of the Department of Physics	SS		
PHY7214	Quantum Optics	L	elective	3	Dean of the Department of Physics	WS		
PHY7219a	Physical-Chemical Analytics 1a, Applied Spectrometry	L	elective	3	Franzke	as needed		

PHY7220a	Physical-Chemical Analytics 2a, Applied Plasma Physics	L	elective	3	Franzke	2-year		
PHY7221a	Physical-Chemical Analytics 3a, Applied Laser Spectrometry	L	elective	3	Franzke	2-year		
PHY7222a	Magnetism II	L	elective	3	Cinchetti	as needed		
PHY7235	Advanced Solid State Physics II – Magnetism and Superconductivity	L	elective	6	Dean of the Department of Physics	WS		
PHY735	Introduction to the Renormalization Group	L	elective	4	Anders	as needed in WS		
PHY738	Hadrons in Quantum Chromodynamics	L	elective	4	Khodjamirian/Hiller	as needed in WS		
PHY7314	Quantum Theory of Semiconductors	L	elective	3	Reiter	as needed		
PHY825	Fundamentals of Detector Physics	L	elective	3	Dean of the Department of Physics	annually in SS		
PHY8210	External School in Particle Physics	L	elective	1	Dean of the Department of Physics	irregular	yes	
PHY8211a	Applications of Synchrotron Radiation	L	elective	3	Zamborlini	SS		
PHY832a	Cosmology	L	elective	3	Dean of the Department of Physics	as needed		
PHY834	Introduction to Renormalization of Quantum Field Theories	L	elective	2	Blümlein	as needed	yes	
PHY835	Introduction to Grand Unified Theories	L	elective	2	Blümlein	as needed	yes	
PHY836	Introduction to Group Theory and Lie Algebras	L	elective	2	Blümlein	SS	yes	
PHY7317	From Standard Model to BSM Physics	L	elective	3	Hiller	SS		
PHY7318	Quantum Information (From Qubits to Black Holes)	L	elective	3	Päs	as needed		
PHY7236	Ultrafast Spectroscopic Methods in Solid State Physics	L	elective	3	Kovalev/Z. Wang	SS		
PHY623	Magnetic Resonance	L(+T)	elective	5	Dean of the Department of Physics	SS		

PHY7233	Practical Aspects of Instrumentation	L(+T)(+S)	elective	3 or 6 or 9	Dean of the Department of Physics	WS/SS		
PHY7219b	Physical-Chemical Analytics 1b, Applied Spectrometry	L+P	elective	5	Franzke	as needed		
PHY7220b	Physical-Chemical Analytics 2b, Applied Plasma Physics	L+P	elective	5	Franzke	2-year		
KM10	Moderne Strahlentherapie	L+P	elective	3	Hammi	WS		
PHY5211	Materials for Nanoelectronics and High-Speed Quantum Electronic Devices	L+S	elective	5	Vitusevich	WS		
PHY912	Methods and Project Planning	L+S	mandatory	15	Dean of the Department of Physics	WS/SS		
PHY421	Instruments of Modern Physics	L+T	elective	5	Khan	as needed		
PHY523a	Statistical Methods of Data Analysis / SMD A	L+T	elective	5	Rhode	SS		yes
PHY523b	Statistical Methods of Data Analysis / SMD B	L+T	elective	5	Rhode	WS		yes
PHY533	Group Theory in Physics I	L+T	elective	6	Dean of the Department of Physics	annual		yes
PHY535	Cosmology, Quantum Cosmology, Gravitational Waves	L+T	elective	9	Päs	as needed		yes
PHY537	Group Theory in Physics II	L+T	elective	5	Löw	as needed		yes
PHY538	Group Theory in Solid State Physics	L+T	elective	6	Bünemann	as needed		yes
PHY621	Electronics	L+T	elective	8	Dean of the Department of Physics	SS		yes
PHY622	Medical Physics I	L+T	elective	8	Dean of the Department of Physics	SS		yes
PHY626	Machine Learning for Physicists	L+T	elective	4	Dean of the Department of Physics	SS		yes
BP12	Physics of Life	L+T	elective	6	Schneider	WS		
PHY631	Advanced Quantum Mechanics	L+T	elective	6	Dean of the Department of Physics	SS		yes

PHY632	Computational Physics	L+T	elective	9	Dean of the Department of Physics	SS		yes
PHY633	Theory of Soft and Biological Matter	L+T	elective	6	Kierfeld	SS		yes
PHY634	General Relativity	L+T	elective	6	Dean of the Department of Physics	SS		yes
PHY712	Accelerator Physics I	L+T	elective	6	Dean of the Department of Physics	WS		yes
PHY714	Molecular Simulation of Soft Matter and Biological Materials	L+T	elective	6	Risselada	WS		
PHY724	Measurement Methods in Surface Physics	L+T	elective	6	Westphal	WS		
PHY7231	Dynamics of Open Quantum Systems	L+T	elective	5	Aßmann	as needed in WS and SS		
PHY7232	Physics of the Top Quark and the Higgs Boson	L+T	elective	6	Dean of the Department of Physics	as needed in SS		yes
PHY7234	Laboratory of Condensed Matter Physics: Time-Resolved Photoemission	L+T	elective	6	Zamborlini	as needed		
PHY731	Introduction to Theoretical Elementary Particle Physics	L+T	specialization or elective	12	Dean of the Department of Physics	annually in WS		yes
PHY732	Introduction to Theoretical Solid State Physics	L+T	specialization or elective	12	Dean of the Department of Physics	WS		yes
PHY733	Quantum Field Theory	L+T	elective	6	Dean of the Department of Physics	annual		yes
PHY7312	Theory of Magnetism in Solids	L+T	elective	6	Bünemann	irregular		
PHY7313	Theory of Soft and Biological Matter	L+T	elective	5	Kierfeld	WS		
PHY811	Flavor Physics in Experiment and Theory	L+T	elective	6	Mannel/Albrecht	as needed in SS		yes

PHY822	Experimental aspects of particle physics	L+T	elective	6	Dean of the Department of Physics	SS		yes
PHY823	Astroparticle Physics	L+T	elective	6	Rhode	SS		
PHY823.2	Astroparticle Physics II	L+T	elective	3	Rhode	WS		
PHY829	Structural Analysis with X-rays	L+T	elective	5	Sternemann/Paulus	SS	yes	
PHY8212	Light-Matter Interaction	L+T	elective	6	Lange	WS		
PHY831	Many-Particle Solid-State Theory	L+T	elective	8	Dean of the Department of Physics	as needed		
PHY832b	Cosmology	L+T	elective	6	Päs	as needed		
PHY833	Flavor Physics	L+T	elective	6	Dean of the Department of Physics	annual		yes
PHY837	Calculation Methods for Feynman Diagrams	L+T	elective	2	Blümlein	as needed	yes	
PHY838	Theory of Soft and Biological Matter II	L+T	elective	5	Kierfeld	as needed		
PHY 839	Advanced Methods in Theoretical High-Energy Physics	L(+T)	elective	2/3	Stamou	WS/SS	yes	
PHY8310	Renormalization in Theoretical High-Energy Physics	L+T	elective	3	Hiller	as needed		
PHY8311	Seminar: Modern Quantum Computing and Quantum Simulation	S	elective	3	Fauseweh	as needed		
PHY7319	Modern Quantum Computing and Quantum Simulation	L+T	elective	6	Fauseweh	SS		
PHY7237	Condensed matter physics: Time-domain Terahertz spectroscopy	L+T	elective	6	Ghalgaoui/Z. Wang	as needed		
PHY7316	Advanced Topics in Quantum Field Theory	L+T/S	elective	6	Stamou	as needed		
PHY812	Accelerator Physics II	L+T+S	elective	6	Dean of the Department of Physics	SS		yes
PHY8214	Introduction to the clinical application of magnetic resonance imaging	L+T+S+P	elective	6	Salehi Ravesh	annual		
PHY8215	Quantitative Magnetresonanztomographie: von Spinanregung zum Bild	S	elective	6	Salehi Ravesh	annual		yes

PHY742	Advanced Laboratory Course for Master Students I	P	mandatory	6	Dean of the Department of Physics	WS		yes
KM09/ APM11	Applied Proton Therapy	P	elective	6	Lühr	SS		
PHY842	Advanced Laboratory Course II: Solid State Physics	P	elective	6	Dean of the Department of Physics	SS		yes
PHY843	Advanced Laboratory Course II: Particle Physics	P	elective	6	Dean of the Department of Physics	SS		yes
PHY844	Advanced Laboratory Course II: Theoretical Course	P	elective	6	Kierfeld	annual		yes
PHY845	Advanced Laboratory Course II: Electronics	P	elective	6	Dean of the Department of Physics	SS		yes
PHY7225	Tandem Projects in Particle Physics	PW+L	elective	6	Kröninger	annual		
PHY911	Research Internship	Research internship	mandatory	15	Dean of the Department of Physics	WS/SS		
PHY515	Physics of Sailing	S	elective	3	Khan, Päs	WS		
PHY528	Nuclear Energy and Other Energy Issues	S	elective	3	Albrecht	WS		
PHY5210S	Magnetism	S	elective	3	Cinchetti	WS/SS		
PHY5214	Physics on ultrashort time scales	S	elective	3	Helml/Khan	WS/SS		
PHY5216	Photovoltaics	S	elective	3	Dean of the Department of Physics	as needed in WS		
PHY6215	Quantum Technologies with Atoms and Photons	S	elective	3	Narevicius/ Weitenberg	SS		
PHY627	Current Topics and Techniques in Surface Physics	S	elective	3	Westphal	as needed		
PHY629	Applied Dosimetry	S	elective	3	Kröninger	annually in WS		
PHY6211	Applications of Machine Learning in Medical Physics	S	elective	3	Dean of the Department of Physics	WS		

PHY7238	Ethics of the Natural Sciences	S	elective	3	Rhode	WS		
PHY713	Soft Matter and Biophysics: Experiment and Theory	S	elective	3	Kierfeld	WS		
PHY722	Current Problems in the Field of Synchrotron Radiation Utilization and Tunneling Microscopy	S	elective	3	Dean of the Department of Physics	WS/SS		
PHY723	Key Experiments in Particle Physics	S	elective	4	Dean of the Department of Physics	annual		
PHY726	Accelerator Physics and Synchrotron Radiation: Applications in Solid State Physics	S	elective	3	Dean of the Department of Physics	WS/SS		
PHY728	Solid State Spectroscopy	S	elective	3	Dean of the Department of Physics	WS/SS		
PHY729	Lasers - Types and Applications	S	elective	3	Dean of the Department of Physics	annual		
PHY7210	Particle and Astroparticle Physics	S	elective	3	Dean of the Department of Physics	WS/SS		
PHY7211	Neutrino and Gamma Astronomy	S	elective	3	Rhode	WS/SS		
PHY7212	Particle Physical Aspects of Cosmic Rays	S	elective	3	Rhode	as needed		
PHY7213	Modern Optics	S	elective	3	Dean of the Department of Physics	SS		
PHY7215	Reading course on particle physics	S	elective	3	Dean of the Department of Physics	WS		
PHY7217	Radio Astronomy	S	elective	3	Rhode	WS		
PHY7218	Cosmic Rays	S	elective	3	Rhode	as needed		
PHY72222b	Magnetism II	S	elective	3	Cinchetti	as needed		
PHY7224	Information Technology of the Future	S	elective	3	Cinchetti	as needed		
PHY7226	Applied Physics in Clinical Medicine	S	elective	3	Schilling	WS		
PHY7227	The Search for New Particles, Dark Matter & Co.	S	elective	3	Kröninger	WS		

PHY7228	Superconducting Technology applied to particle accelerators	S	elective	3	Velez Saiz	WS	yes	
PHY7229	Terahertz Dynamics of Condensed Matter	S	elective	3	Lange/Z. Wang	WS/SS		
PHY7230	Quantum Technologies	S	elective	3	Aßmann	as needed in WS and SS		
PHY7238	Quantum simulation with cold atoms and molecules	S	elective	3	Narevicius/ Weitenberg	WS		
PHY7239	Particle Physics meets Astroparticle Physics	S	elective	3	Albrecht	as needed		
PHY734	Theory of Strongly Correlated Systems and Quantum Information	S	elective	3	Dean of the Department of Physics	WS/SS		
PHY736	Physics Beyond the Standard Model (BSM Seminar)	S	elective	3	Dean of the Department of Physics	WS/SS		
PHY737	Theoretical Problems of Condensed Matter	S	elective	3	Dean of the Department of Physics	SS/WS		
PHY739	Differential Geometry / General Relativity	S	elective	5	Löw/Schwachhöfer	irregular		
PHY7310	Big Questions	S	elective	3	Päs	WS		
PHY7311	Neutrinos and Cosmology	S	elective	3	Päs	WS		
PHY7315	Ask me anything: Quantum Dots	S	elective	3	Reiter	as needed		
PHY826	Detector systems in particle and medical physics	S	elective	3	Dean of the Department of Physics	WS		
PHY827	False Discoveries in Particle Physics	S	elective	3	Dean of the Department of Physics	as needed		
PHY8211b	Applications of Synchrotron Radiation	S	elective	3	Zamborlini	SS		
PHY8213	Light-Matter Interaction	S	elective	3	Lange	WS		
PHY8216	Ultrafast spintronics and light driven magnetisation dynamics	S	elective	3	Kovalev/Z. Wang	SS		
PHY846	Condensed Matter Theory Laboratory Course	S	elective	3	Kierfeld	annual		yes
PHY1011	Master’s thesis	Supervised research	mandatory	30	Dean of the Department of Physics	WS/SS		

PHY921	Particle physics meets industry	S	elective	3	Kröninger	WS/SS		yes
	English for Physics C1	T	elective	6	zhb	WS		
	Thin film growth: From low-dimenaional physics to industrial applications	L+T	elective	6	Bedoya-Pinto	WS		

Module: Basic Concepts of Physics (**PHY412a**)				
Degree Program: Physics (M.Sc.)				
Frequency: in SS	**Duration:** 1 semester	**Semester:** 2nd - 4th sem.	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	6	3
2	**Language:** English				
3	**Content** Part I: From Antiquity to Classical Field Theory: Ancient astronomy, symmetries, atomism and element theory in antiquity, the Aristotelian worldview, Medieval criticism of Aristotele, astronomy before Copernicus, Galileo, Kepler and the Copernican Revolution, the foundation of the experimental method, physics between technology and metaphysics (Francis Bacon; Descartes), Newton's optics: Experimental Phenomena and where do they originate from, Newton's Principia: Mass, Force and Gravitation; "Rules of Philosophizing," Space and Time, Leibniz-Clarke Debate, the "Living Force," Concept of Energy, Conservation of Energy, Electromagnetism, Concept of Field (Oerstedt, Faraday, Maxwell), Theory of Relativity (Einstein) Part II: From the probabilistic revolution to quantum theory: Laplace: determinism and probability. Probabilistic revolution, energy conservation law; entropy concept and 2nd Law of Thermodynamics, Kinetic Theory of Heat, Maxwell and Boltzmann, Entropy Theorem, Radiation Theory and Planck's "Desperate Remedy", Einstein's Light Quantum Hypothesis, Rutherford Scattering and Bohr's Model of the Atom, Quantum Mechanics of 1925/26: Heisenberg, Schrödinger, Born; Heisenberg's uncertainty principle and Bohr's "Copenhagen" interpretation; Bohr-Einstein debate, EPR thought experiment, Schrödinger's cat, Bohm's hidden parameters and Everett's "Many Worlds," decoherence, quantum mechanics and thermodynamics, wave-particle duality. Introductory literature: Koestler, Die Nachtwandler; Hund, Geschichte der physikalischen Begriffe; Laue, Geschichte der Physik; Mason, Geschichte der Naturwissenschaft; Lasswitz, Geschichte der Atomistik; Lange, Geschichte des Materialismus; Hunger, Von Demokrit bis Heisenberg; Sambursky, Der Weg der Physik; Scheibe, Die Philosophie der Physiker; Further details in the lecture.				
4	**Learning outcome** Students will learn to identify the historical conditions under which our current physical worldview emerged. The emergence of the basic concepts in which the physical worldview is formulated (space, time, matter, causality, fields, probability, quanta, and others) is learned. Employing concepts from the interdisciplinary boundary between physics and philosophy (epistemology, philosophy of science), this historical context is used to show how physical research can be justified and how physical theories are established and tested. Pedagogical aspects and connotations are conveyed, that will be helpful for teaching at schools or universities. The aim of the course is to teach a competent and critical approach to the justification of research and its development				

5	**Examination** Course credit: Written paper. Graded oral module examination (30 min)	
6	**Participation Requirements**	
7	**Module type** Elective module	
8	**Responsible** Prof. W. Rhode	**Faculty in charge** Department of Physics

Module: Basic Concepts of Physics (**PHY412b**)				
Degree Program: Physics (M.Sc.)				
Frequency: in SS	**Duration:** 1 semester	**Semester:** 2nd - 4th sem.	**Credits** 5	**Work load** 150 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	5	3
2	**Language:** English				
3	**Content** Part I: From Antiquity to Classical Field Theory: Ancient astronomy, symmetries, atomism and element theory in antiquity, the Aristotelian worldview, Medieval criticism of Aristotele, astronomy before Copernicus, Galileo, Kepler and the Copernican Revolution, the foundation of the experimental method, physics between technology and metaphysics (Francis Bacon; Descartes), Newton's optics: Experimental Phenomena and where do they originate from, Newton's Principia: Mass, Force and Gravitation; "Rules of Philosophizing," Space and Time, Leibniz-Clarke Debate, the "Living Force," Concept of Energy, Conservation of Energy, Electromagnetism, Concept of Field (Oerstedt, Faraday, Maxwell), Theory of Relativity (Einstein) . Part II: From the probabilistic revolution to quantum theory: Laplace: determinism and probability. Probabilistic revolution, energy conservation law; entropy concept and 2nd Law of Thermodynamics, Kinetic Theory of Heat, Maxwell and Boltzmann, Entropy Theorem, Radiation Theory and Planck's "Desperate Remedy", Einstein's Light Quantum Hypothesis, Rutherford Scattering and Bohr's Model of the Atom, Quantum Mechanics of 1925/26: Heisenberg, Schrödinger, Born; Heisenberg's uncertainty principle and Bohr's "Copenhagen" interpretation; Bohr-Einstein debate, EPR thought experiment, Schrödinger's cat, Bohm's hidden parameters and Everett's "Many Worlds," decoherence, quantum mechanics and thermodynamics, wave-particle duality. Introductory literature: Koestler, Die Nachtwandler; Hund, Geschichte der physikalischen Begriffe; Laue, Geschichte der Physik; Mason Geschichte der Naturwissenschaft; Lasswitz, Geschichte der Atomistik; Lange, Geschichte des Materialismus; Hunger, Von Demokrit bis Heisenberg; Sambursky, Der Weg der Physik; Scheibe, Die Philosophie der Physiker; Further details in the lecture.				
4	**Learning outcome** Students will learn to identify the historical conditions under which our current physical worldview emerged. The emergence of the basic concepts in which the physical worldview is formulated (space, time, matter, causality, fields, probability, quanta, and others) is learned. Employing concepts from the interdisciplinary boundary between physics and philosophy (epistemology, philosophy of science), this historical context is used to show how physical research can be justified and how physical theories are established and tested. Pedagogical aspects and connotations are conveyed, that will be helpful for teaching at schools or universities. The aim of the course is to teach a competent and critical approach to the justification of research and its development.				
5	**Examination** Graded oral module examination (30 min)				

6	**Participation Requirements**	
7	**Module type** Elective module	
8	**Responsible** Prof. W. Rhode	**Faculty in charge** Department of Physics

Module: Instruments of Modern Physics (**PHY421**)				
Degree Program: Physics (M. Sc.)				
Frequency: As needed	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 5	**Work load** 150 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact**
	1	Lecture + Tutorial	L + T	5	3

2 Language: English

3 Content

1. **Introduction:**
   Review of electrodynamics and special relativity, light and particle optics, Signal processing, introduction to programming (for some practice problems).
2. **Sources of electromagnetic radiation:**
   Black body, discharge lamps, laser systems, X-ray tubes, synchrotron radiation sources, free-electron lasers, optical laboratory equipment.
3. **Sources of particle radiation:**
   Cosmic rays, radioactive preparations, accelerators, and storage rings.
4. **Particle detectors:**
   Interaction of radiation with matter, ionization chambers, semiconductor detectors, photomultipliers, scintillators, Cherenkov effect, and transition radiation.
5. **Examples of detection techniques and applications:**
   Detectors in particle and astroparticle physics, gravitational wave detectors, scanning probe microscopes, imaging in medical physics.
6. **Other instruments:**
   Electrical measuring instruments, atomic clocks, superconducting magnets, vacuum technology

4 Learning outcome

Students are provided with an overview of instruments and experimental techniques that they may encounter during their studies as well as in their professional practice in a physics laboratory. Emphasis is placed on radiation sources and detectors, but other instruments and digital processing of electrical signals are also addressed. Exercises will include questions testing basic understanding, simple calculations, and simulations using a scripting language (Matlab or Python). Programming skills are not a prerequisite, but will be learned during the exercises through practical application to physical problems.

5 Examination

Graded oral module exam (30 min).
Admission requirements: Regular and active participation in the exercises as well as successful completion of the exercises. Details will be announced at the beginning of the lecture.

6 Participation Requirements

7 Module type

Elective module

8	**Responsible** Prof. Shaukat Khan	**Faculty in charge** Department of Physics

Module: Physics of Sailing (**PHY515**)				
Degree Program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure** 2 contact hours per week Seminar. Self-study and own presentations. The seminar consists of presentations by students on topics related to the physics of sailing.	
2	**Language:** English	
3	**Content** Experimental methods and theoretical concepts from physics are applied to topics related to sailing, i.e., the locomotion of watercraft using wind energy. These include, among others: • Rig mechanics • Aerodynamics • Yacht stability • Weather and wind systems • Waves • Astronomical navigation • Polynesian navigation • GPS • Radio • Radar • Regatta sailing • Seasickness	
4	**Learning outcome** Students learn how a wide variety of experimental methods and theoretical concepts in physics are used and complement each other in a specific, applied problem area. In addition, students also acquire presentation techniques for conveying knowledge and discussion techniques.	
5	**Examination** Course Credits: Active participation in the discussions following the lectures. Module examination: Graded own presentation	
6	**Participation requirements**	
7	**Module type** Elective module	
8	**Responsible** Prof. S. Khan, Prof. H. Päs	**Faculty in charge** Department of Physics

Module: Statistical Methods of Data Analysis / SMD A (**PHY523a**)				
Degree Program: Physics (M.Sc.)				
Frequency: in SS	**Duration:** 1 semester	**Semester:** 2nd sem.	**Credits** 5	**Work load** 150 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture + Excercise	L+T	5	2 + 1
2	**Language:** English				
3	**Content** **SMD A: From raw data to signal subsurface separation:** Numerical methods of data processing, data handling and programming, algorithms and data structures, methods of linear algebra, probability theory, one and multidimensional distributions, random numbers and Monte Carlo methods, data mining methods: Discriminant Analysis, Principal Component Analysis, Feature Selection, Supervised Learning (kNN, Decision Trees, Random Forests), MRMR, Unsupervised Learning (Ensemble Learner), Convolutional Neural Nets and others.				
4	**Learning outcome** Today, data are usually collected electronically. The students learn the appropriate handling of statistical methods for the analysis of moderate to very large amounts of data, following the the temporal sequence of a data analysis. The exercises are solved (also) on the computer using current software. In the course, practical competence in data analysis is acquired for the preparation of theses and later professional practice.				
5	**Examination** Course Credits: Active participation in the exercises of SMD A. Module examination: written or oral. The form of examination will be announced at the beginning of the semester.				
6	**Participation Requirements** Favorable: Programming knowledge in a suitable language, e.g. Python; Recommended: Participation in the Toolbox Workshop The SMD A event should be heard before the SMD B event.				
7	**Module type** Elective module				
8	**Responsible** Prof. W. Rhode		**Faculty in charge** Department of Physics		

Module: Statistical Methods of Data Analysis / SMD B (**PHY523b**)				
Degree Program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st/3rd sem.	**Credits** 5	**Work load** 150 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	2	Lecture with exercise	L+T	5	2 + 1
2	**Language:** English				
3	**Content** **From measurement data to physical measurement points and statements.** Parameter estimation, optimization problems, least squares method, maximum likelihood method, numerical fit methods, goodness-of-fit, regularization, confidence intervals and hypothesis testing, parameterization of data, Bayesian methods, methods for solving inverse problems and their evaluation, validation techniques, treatment of systematic errors, acceptance calculation.				
4	**Learning outcome** Today, data are usually collected electronically. The students learn the appropriate handling of statistical methods for the analysis of moderate to very large amounts of data, following the temporal sequence of a data analysis. The exercises are solved (also) on the computer using current software. In the course, practical competence in data analysis is acquired for the preparation of theses and for later professional practice.				
5	**Examination** Course Credits: Active participation in the exercises of SMD B. Module examination: written or oral. The form of examination will be announced at the beginning of the semester.				
6	**Participation Requirements** Favorable: Programming knowledge in a suitable language, e.g. Python; Recommended: Participation in the Toolbox Workshop The SMD A event should be heard before the SMD B event.				
7	**Module type** Elective module				
8	**Responsible** Prof. W. Rhode		**Faculty in charge** Department of Physics		

Module: Physics and Technology of Arms Limitation Treaty Verification (**PHY524**)				
Degree Program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	2
2	**Language:** English				
3	**Content** Use of physics for verification of compliance with arms limitation agreements. Current research of the teacher about IAEA verification and safeguards is part of the syllabus. Includes an introduction to arms limitation and the importance of verification.				
4	**Learning outcome** Students learn the physical basis for the various verification techniques. Elementary formulas are derived and numerical examples for practical applications are discussed. For the so-called national technical means of verification these are: Orbits of satellites, optical imaging with diffraction limitation of image resolution and sensor techniques, radar with radar equation and imaging with synthetic aperture. Cooperative means are nuclear radiation detection, seismic and acoustic (infrasound, underwater sound) detection of nuclear explosions, techniques for missile container control and missile launch monitoring, labels, seals, and ground sensors. Current research for new verification technology is covered with examples (acoustic seismic land and aircraft detection, monitoring of an underground repository, noble gas detection). The lecture concludes with current negotiations and proposals for them, as well as policy issues related to verification. With the discussion of the importance of verification for arms limitation in general, the presentation of verification rules and techniques of different limitation treaties and the treatment of historical aspects in their establishment, relations between natural science and society or international politics are addressed and interdisciplinary skills are strengthened. Elementary knowledge in arms control and disarmament is taught. Students recognize the importance of natural science for disarmament and peace and gain insight into current verification research in natural science. Attention to social aspects of their own science and the responsibility of natural scientists is increased.				
5	**Examinations** Module examination: Graded oral examination (20 min)				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Dr. J. Altmann		**Faculty in charge** Department of Physics		

Module: Statistical Methods of Data Analysis 2 (**PHY525**)				
Degree Program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 week block course	**Semester:** 1st sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	Block course
2	**Language:** English				
3	**Content** Building on the lecture "Statistical Methods of Data Analysis", the course covers coverage probabilities (frequentist vs. Bayesian confidence intervals), deepening of the method of least squares with emphasis on applications with low statistics and not a priori known variances, application of multivariate selection methods, deconvolution using density mixture models and as a parameterization problem, Markov Chain, Monte Carlo, separation of signal and background using sWeights, event-by-event efficiencies, harmonic analysis and Lomb periodogram, robust statistics.				
4	**Learning outcome** Students will gain advanced insights into statistical analysis of data, building on lecture PHY523, "Statistical Methods of Data Analysis"				
5	**Examination** Examination: Written module examination (90min) or oral module examination depending on the number of participants.				
6	**Participation Requirements:** Desired: Programming knowledge in a suitable language (FORTRAN, C, JAVA, C++, or similar)				
7	**Module type** Elective module				
8	**Responsible** Prof. W. Rhode	**Faculty in charge** Department of Physics			

Module: Nuclear Energy and Other Energy Issues (**PHY528**)				
Degree Program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module Structure:** 2 contact hours per week seminar, self-study and own presentation.	
2	**Language:** English	
3	**Content** Fundamentals of nuclear and reactor physics, reactor design types, reactor safety aspects and accidents, fuel cycle, final disposal and reactor decommissioning, energy storage, aspects of other forms of energy, energy supply.	
4	**Learning outcome** The seminar is an introduction to the topic of nuclear energy in the context of energy supply. In particular, various aspects of reactor physics are highlighted and related to each other. The embedding of the topic in current issues also places the events in a social context. Independent research as well as presentation techniques are also trained.	
5	**Examination** Course Credits: Active participation in the discussions following the lectures. Module examination: Graded own presentation on a seminar topic.	
6	**Participation requirements**	
7	**Module type** Elective module	
8	**Responsible** Prof. J. Albrecht	**Faculty in charge** Department of Physics

Module: Magnetism **(PHY5210L)**				
Degree Program: Physics (M.Sc.)				
Frequency: annually	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	6	4

2 Language: English

3 Content

1. **Basic concepts and building blocks of magnetism:** magnetic moments, magnetic fields, magnetic susceptibility, classification of magnetic materials.
2. **Magnetism of atoms/ions and localized magnetic moments:** atomic diamagnetism, atomic paramagnetism, influence of crystal field in solids.
3. **Magnetism of conduction electrons:** Landau Diamagnetism, Pauli Paramagnetism, Band Ferromagnetism.
4. **Exchange interaction:** direct and indirect exchange, super exchange, double exchange, RKKY interaction. Heisenberg model and Hubbard model for the description of magnetically ordered materials, magnetic order structures and phase transitions.
5. **Collective magnetism:** ferromagnetism, antiferromagnetism, ferrimagnetism, magnetic anisotropy, magnetic domain, spin waves, and stoner excitations.

4 Learning outcome

Students gain insight into the physical principles of the description of magnetic materials, and into the most important magnetic phenomena. They will be able to apply these concepts to concrete physical situations; for example, they will be able to understand the operation of many applications in the field of information and communication technology.

5 Examination

Module examination: Graded oral examination (30 min)

6 Participation requirements

7 Module type

Elective module

8	**Responsible**	**Faculty in charge**
	Prof. M. Cinchetti	Department of Physics

Module: Magnetism (**PHY5210S**)				
Degree Program: Physics (M.Sc.)				
Frequency: every semester	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 3	**Work load** 60 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Conta**
	1	Seminar	S	3	2
2	**Language:** English				
3	**Content** The seminar will include lectures on various topics relevant to current research in magnetism. Among others: Measurement methods, materials, and technologically relevant effects.				
4	**Learning outcome** The seminar is intended as a supplement to the lecture Magnetism. Students will gain insight into the physical principles of the description of magnetic materials and into the most important magnetic phenomena. They will be able to apply these concepts to concrete physical situations, especially in areas that are currently the focus of research in magnetism. For example, they can understand the operation of many applications in the field of information and communication technology.				
5	**Examination** Module examination: own oral presentation				
6	**Participation requirements** In parallel in participation in the lecture Magnetism PHY5210L.				
7	**Module type** Elective module				
8	**Responsible** Prof. M. Cinchetti	**Faculty in charge** Department of Physics			

Module: Materials for Nanoelectronics and High-Speed Quantum Electronic Devices (**PHY5211**)				
Degree Program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 5	**Work load** 150 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	2
	2	Self-study and own presentation	S	2	1
2	**Language:** English				
3	**Content** In the lecture the essential basics of the following topics are covered: 1. Overview of the most important material systems and their application in nanoelectronic devices; 2. Transport mechanisms in quantum electronic devices, such as resonant tunnel structures; 3. Basics and applications of noise spectroscopy; 4. Properties of solid state structures in different dimensions and information technologies; 5. Advanced nanostructures based on biocompatible materials for high speed biosensors.				
4	**Learning outcome** Students gain insight into the fundamentals of nanotechnology: nanostructures, micro and nano fabrication of structures and their applications. Students will learn the state of the art of research in the areas of application of noise spectroscopy to study the transport properties of electronic nanodevices. The relevant concepts of the research field are presented, methodologically substantiated and illustrated with examples.				
5	**Examination** Course Credits: Active participation in the discussions following the lectures. Module examination: Graded own presentation on a topic from current research.				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Prof. S. Vitusevich		**Faculty in charge** Department of Physics		

Module: Physics on ultrashort time scales (**PHY5214**)				
Degree Program: Physics (M.Sc.)				
Frequency: as required	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours**
	1	Seminar	S	3	2
2	**Language:** English				
3	**Content** We discuss together each week a fundamental or recent publication from a well-known scientific journal such as *Science* and *Nature* in the field of **attosecond or X-ray physics.** Even though all of these articles are interesting, they are also typically very compact and, thus, often not easy to understand. Our joint discussion in the Journal Club promises a more pleasant (first?) access to technical literature than the solitary study at home.				
4	**Learning outcome** At the beginning of the seminar, a student briefly presents the respective article (with slides, on the blackboard, with table presentation), and then the whole group discusses it. The aim is to develop a deeper understanding of the described contexts and to develop an independent approach to the study of technical literature. Scientific questions that are not directly related to the article can also be discussed at any time. For a fruitful discussion, the non-presenting participants should also have studied the article before the seminar.				
5	**Examination** Module examination: Graded own presentation at the presentation of the publication.				
6	**Participation requirements** Basic knowledge of optics and laser physics.				
7	**Module type** Elective module				
8	**Responsible** JProf. W. Helml/Prof. S. Khan		**Faculty in charge** Department of Physics		

Module: Photovoltaics (**PHY5216**)				
Degree Program: Physics (M.Sc.)				
Frequency: as needed in WS	**Duration:** 1 semester	**Semester:** 1st sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours**
	1	Seminar	S	3	2
2	**Language:** English				

3 Content

The seminar deals with the physical fundamentals of photovoltaics. In addition to these fundamentals, methods of analysis and optimization of photovoltaic systems as well as technical implementation are discussed. Especially for students not familiar with the subject, lectures on current topics currently discussed in politics such as smart grids will also be offered. Specifically, it is planned to cover the following topics:

- Optical properties of conventional semiconductors
- Doping, p-n and p-i-n transitions
- solar radiation, Schottky-Queisser limit
- Design of real solar cells, optimization of the fill factor
- Multi-junction solar cells
- Coatings and nanostructuring: optimizing efficiency
- Solar cells from organic semiconductors
- novel solar cells: Thin film solar cells, perovskites
- commercial aspects of photovoltaics
- Challenges and opportunities of integrating solar power into the existing power grid infrastructure

4 Learning outcome

Students apply the concepts of modern semiconductor physics to understand the operation of modern solar cells and their optimization. These topics are embedded in the context of sustainable technologies and renewable forms of energy.

5 Examination

Module examination: graded oral seminar presentation

6 Participation requirements

7 Module type

Elective module

8	**Responsible** Dean of the Department of Physics	**Faculty in charge** Department of Physics

Module: Einführung in die Quantentechnologien (**PHY5218**)				
Degree Program: Physics (M.Sc.)				
Frequency: Winter term	**Duration:** 1 semester	**Semester:** 5th B.Sc.	**Credits** 3	**Work load** 90 h

1	**Module Structure:**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	2
2	**Language:** German				
3	**Content** Introduction to modern quantum technologies 1. Basic concepts: entanglement, qubits, quantized light fields, squeezing 2. overview of quantum technology pillars: quantum computing, quantum simulation, quantum communication, quantum sensing and metrology 3. overview of quantum technology platforms: atoms, molecules, ions, photons, polaritons, superconducting circuits, quantum dots 4. detailed discussion of a few examples				
4	**Learning outcome** Students obtain an overview of quantum technologies and the connection to current research at TU Dortmund as a basis for more in-depth lectures.				
5	**Examination** Module exam: graded examination (written or oral depending on number of participants)				
6	**Participation Requirements** Physics IV				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics		**Faculty in charge** Department of Physics		

Module: Group Theory in Physics I (**PHY533**)				
Degree program: Physics (M.Sc.)				
Frequency: Annual	**Duration:** 1 semester	**Semester:** 1st-3rd sem.	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture with exercise	L+T	6	2 + 2
2	**Language:** English				
3	**Content** Fundamentals of group theory and Lie groups, in particular with applications in elementary particle physics: symmetries in quantum mechanics; basic concepts of group theory (definition, discrete groups, the permutation group S_n, side classes, factor group, subgroups); representations of groups (reducible and irreducible representations, Schur's lemma); the angular group, SO(3) and SU(2) (angular momentum algebra, irreducible representations, tensor operators, Wigner-Eckart theorem); general structure of Lie algebras (Cartan algebra, roots and weights); the group SU(3) (representations, quark model); tensor methods and Young tableaux; Dynkin diagrams and classification of semisimple Lie groups, relation to unified field theories (SU(5)), and to the quark model (SU(6)). Literature: H Georgi: Lie Algebras in Particle Physics, Reading, Mass. 1982; Wu-Ki Tung, Group Theory in Physics, Singapore 1985; D. B. Lichtenberg, Unitary Symmetry and Elementary Particles, New York 1970.				
4	**Learning outcome** Students learn how to mathematically grasp the fundamental concept of a symmetry of nature. They learn to use the symmetry concepts already introduced heuristically in quantum mechanics and in the experimental and theoretical introductions to elementary particle physics and to place the corresponding algebraic constructs into a mathematical building. They will learn new forms of possible symmetries. They learn how to construct more general hypotheses or theories from them, as they play a central role in modern elementary particle physics.				
5	**Examination** Written exam (120 min) or oral module exam (30 min)				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Module Officer(s)** Dean of the Department of Physics	**Faculty in charge** Department of Physics			

Module: Introduction to Quantum Field Theory of Elementary Particles (**PHY534**)				
Degree Program: Physics (M.Sc.)				
Frequency: As needed	**Duration:** Block course	**Semester:** 1st/2nd sem.	**Credits** 3	**Work load** 60 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	22 h block
2	**Course Language:** English				
3	**Content** **Classical Field Theory:** Hamilton-Jacobi theory of fields in Minkowski space, Lagrange formalism, Poisson brackets, energy-momentum tensor, Noether theorem in CFT, internal charges, equations of motion, all classical fields of the Standard Model with and without spin **Canonical Quantization of Scalar Fields:** commutation relations, creation and annihilation operator representations, quantized Hamiltonian, normal ordering, charged scalar fields, charge and number density operators **Greens Functions:** general time ordering and T* ordering, scalar propagators in Minkowski space **Path Integral Quantization:** quantum mechanical path integral and examples, QFT path integrals, perturbative treatment by functional derivative, interacting scalar fields, derivation of Feynman rules **Fermion Fields:** functional quantization of the Dirac field, anti-commutators, gauge-phase transformation, properties of Grassmann variables, fermionic path integral for free Dirac fields, derivation of Green's functions **Yang-Mills Fields:** derivation of gauge invariance for general non-Abelian groups, Faddeev-Popov formalism **WT-identities and BRS Formalism:** path-integral derivation of Ward-Takahashi identities, the BRS-formalism of Yang-Mills QFTs and the implementation of gauge-phase invariance in the quantized case				
4	**Learning outcome** Students will gain initial insights into fundamental aspects of relativistic quantum field theory of the various parts of the Standard Model of elementary particles from problem definition to the building blocks for concrete calculations.				
5	**Examinations** Course work: 50% of the points in the exercises Module examination: Graded oral examination (30 min)				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Prof. J. Blümlein		**Faculty in charge** Department of Physics		

Module: Cosmology, Quantum Cosmology, Gravitational Waves (**PHY535**)				
Degree Program: Physics (M.Sc.)				
Frequency: As needed	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 9	**Work load** 270 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture with exercise	L + T	9	4+2
2	**Language:** English				
3	**Content** Gravitation and Robertson-Walker metric, Thermal evolution in the universe, primordial nucleosynthesis, Recombination, Structure formation, Baryogenesis, Dark matter, Dark energy, Inflation, Gravitational waves, Quantum cosmology.				
4	**Learning outcome** Students gain insight into the foundations of cosmology and learn basic knowledge of how important processes in the early universe are described and predictions calculated. They learn to describe and analyze processes such as generation of dark matter, baryon asymmetry or inflation.				
5	**Examinations** Module examination: Graded oral examination (30 min)				
6	**Participation requirements** recommended General Relativity				
7	**Module type** Elective module				
8	**Responsible** Prof. H. Päs		**Faculty in charge** Department of Physics		

Module: Group Theory in Physics II (**PHY537**)				
Degree program: Physics (M.Sc.)				
Frequency: as needed	**Duration:** 1 semester	**Semester:** 1st-3rd sem.	**Credits** 5	**Work load** 150 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture with exercise	L+T	5	2 + 1
2	**Language:** English				
3	**Content** Infinite-dimensional Lie groups, conformal mappings in d=2 and d=4. The Virasoro algebra, central extension of algebras. The role of the energy-momentum tensor, Conformal Towers. Computation of correlations in the framework of conformal field theories. Critical exponents. Minimal models. Literature: Di Franceso, Pierre Mathieu, David Sénéchal Conformal Field Theory, Springer Fradkin, Palchik. Conformal Quantum Field Theory in D-dimensions, Springer				
4	**Learning outcome** Students learn how the basic concept of conformal mappings applies to various areas of theoretical physics. They learn to understand the connection to the scaling laws already known from thermodynamics and dealing with infinite-dimensional Lie groups and their extensions. You will learn new forms of possible symmetries that are important in both elementary particle theory and thermodynamics.				
5	**Examination** Module examination: Graded oral examination (30 min)				
6	**Participation requirements** Recommended: knowledge of group theory in Physics and elementary particle theory				
7	**Module type** Elective module				
8	**Responsible** PD U. Löw		**Faculty in charge** Department of Physics		

Module: Group Theory in Solid State Physics (**PHY538**)				
Degree Program: Physics (M.Sc.)				
Frequency: As needed	**Duration:** 1 semester	**Semester:** 1st-3rd sem.	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture with exercise	L+T	6	3+1
2	**Language:** English				
3	**Content** Group theory basics; representations and characters; orthogonality theorems; relation between quantum mechanics and group theory; the 32 point groups in solids; irreducible representations of point groups; double point groups; group theory in time-independent perturbation theory: splitting of atomic orbitals in solids; group theory evaluation of matrix elements: Wigner-Eckart theorem; Space groups and their irreducible representations; particles in periodic potentials. Literature: H.-W. Streitwolf, Group Theory in Solid State Physics; M. Böhm, Symmetries in Solids; M.S. Dresselhaus et al, Group Theory.				
4	**Learning outcome** Students learn the mathematical foundations of group theory and, in particular, the concept of irreducible representations of groups. Starting from these basics, they are taught the fundamental relationship between group theory and the properties of quantum mechanical systems. In the lecture and in the exercises, the students then deal in detail with the groups that are particularly important in solids, the point groups, the double point groups and the space groups.				
5	**Examination** Module exam: oral exam (30 min)				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Dr. J. Bünemann		**Faculty in charge** Department of Physics		

Module: Electronics (**PHY621**)				
Degree Program: Physics (M.Sc.)				
Frequency: in SS	**Duration:** 1 semester	**Semester:** 2nd sem.	**Credits** 8	**Work load** 240 h

1 Module structure

No.	Element / Course	Type	Credits	Contact hours per week
1	Lecture with exercise	L+T	6	3+2

Lecture and self-study, the exercise consists of a theoretical and practical part

2 Course Language: English

3 Content

Basic properties of electrical and electronic components, methods of measurement recording.

Behavior and characteristics of a diode, small signal behavior and limit data of operation, static and dynamic behavior in the model, applications with particular diodes; characteristics, operating point and small signal behavior of bipolar transistors, basic circuits with diodes and bipolar transistors, characteristics, operating point of field effect transistors, source, gate and drain circuits; amplifiers: Current sources, current mirrors, differential amplifiers, operating point, operational amplifiers, principle of negative feedback, typical applications of operational amplifiers; flip-flop circuits, use of gates, comparators, Schmitt triggers, digital technology basics: logical basic functions, derived basic functions; switching networks: Number representation, adders. Applications: Impedance converters, filters, power supplies, measurement circuits, sensors.

Literature:
Tietze/Schenk, Semiconductor Circuit Technology,
K.H. Rohe: Electronics for Physicists,
P. Horowitz /W. Hill: The Art of Electronics,
R. Heinemann: PSPICE, Introduction to Electronics Simulation

4 Learning outcome

The students classify the typical building blocks, components and methods of electronics. Using standard examples, they identify and characterize components in circuits. In the exercises, the students deepen their theoretical knowledge as a supplement to the lecture by means of example tasks. Furthermore, they transfer their knowledge to real circuits, accompanying the lecture. In the exercises the students develop their social competences in groups of two. For this purpose, they realize circuits and standard measurement setups in team work in small working groups.

5 Examination

Course Credits: Homework and practical realization in the exercises
Module examination: Graded written exam (180min)

6 Participation requirements

7 Module type

Elective module

8 Responsible	**Faculty in charge**
Dean of the Department of Physics	Department of Physics

Module Medical Physics I (**PHY622)**				
Degree Program: Physics (M.Sc.)				
Frequency: in SS	**Duration:** 1 semester	**Semester:** 2nd sem.	**Credits** 8	**Work load** 240 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture with exercise	L+T	8	3 + 2
2	**Course Language:** English				
3	**Content** Physical principles and techniques for medicine The module includes 3 areas: 1. **Physics of life** Fundamentals for understanding medically relevant processes such as blood circulation, respiration, biomechanics, ear, eye. 2. **Physical techniques for diagnostics** Emphasis on imaging techniques such as X-ray imaging, magnetic resonance imaging, ultrasound, positron emission tomography, magnetic and electrical sources 3. **Physical methods for therapy** Ionizing radiation, radiation protection, lasers in medicine Literature: Medical Physics, Volumes 1-3: J. Bille, W. Schlegel (eds.). Biophysics: R. Glaser. Biophysics: W. Hoppe, W. Lohmann, H. Markl, H. Ziegler (eds.). Imaging Techniques in Medicine: O. Dössel.				
4	**Learning outcome** The students know the physical phenomena which are of particular relevance in medical examinations and methods. They learn the most important examination techniques and therapeutic methods for medical practice.				
5	**Examination** Course Credits: Homework. Module examination: Graded written exam (180min)				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics		**Faculty in charge** Department of Physics		

Module: Magnetic Resonance (**PHY623**)				
Degree Program: Physics (M.Sc.)				
Frequency: in SS	**Duration:** 1 semester	**Semester:** 2nd sem.	**Credits** 5	**Work load** 150 h

1	**Module structure** 3 contact hours per week lecture, optional exercise. Possibility of practical supplementation by laboratory experiments.	
2	**Language:** English	
3	**Content** **Fundamentals and applications of magnetic resonance:** Classical and quantum mechanical description of the main interactions; manipulation and time evolution of spin systems; imaging techniques; experimental implementation: spectrometers, metrology; applications related to the study of structure and dynamics of hard as well as soft matter; in particular, the applications from the material science and medical physics fields will be adapted to the audience. Literature: Slichter: Principles of magnetic resonance, Levitt: Spin dynamics, Schweiger, Jeschke: Principles of Pulse Electron Paramagnetic Resonance	
4	**Competences** The students gain an overview of different fields of magnetic resonance and know the most important methods and the range of basic applications. Furthermore, the students are able to read the original literature with profit and they can perform simple calculations on spin dynamics independently.	
5	**Examination** Course Credits: optional Homework. Module examination: Graded oral examination (30 min)	
6	**Participation requirements**	
7	**Module type** Elective module	
8	**Responsible** Dean of the Department of Physics	**Faculty in charge** Department of Physics

Module: Machine Learning for Physicists (**PHY626**)				
Degree Program: Physics (M.Sc.)				
Frequency: in SS	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 4	**Work load** 120 h

1	**Module Structure:**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture with Excercise	L +T	8	1 + 1
2	**Language:** English				
3	**Content** Different methods and applications of machine learning will be presented in order to be directly used by the students in practical exercises. The focus is on deep learning methods, such as deep neural networks (DNNs), convolutional neural networks (CNNs) and feedback neural networks (RNNs). Exercises are conducted in Jupyter notebooks, and modern software libraries such as Keras, Tensorflow, and Scikit-Learn are used.				
4	**Learning outcome** Participants learn to apply modern machine learning methods to given problems. The methods learned are then applied to a data analysis problem posed by themselves and both the solution and the results are documented in a project report.				
5	**Examination** Course work: work on the exercises and presentation of the solutions Module exam: graded project report				
6	**Participation Requirements** Basic knowledge in Python, desirable is the lecture 'Statistical Methods of Data Analysis'.				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics	**Faculty in charge** Department of Physics			

Module: Current Topics and Techniques in Surface Physics (**PHY627**)				
Degree Program: Physics (M.Sc.)				
Frequency: As needed	**Duration:** 1 semester	**Semester:** 2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	S	3	2
2	**Language:** English				
3	**Content** 1. **Solid state physics:** symmetry, space groups, densities of states, crystal potential, band structure, orbital hybridization. 2. **Surface physics:** preparation, characterization and analysis ofatomic, electronic and vibronic surface structures, surface states, reconstructions, relaxation, dangling bonds, surface tension 3. **Molecular interactions:** Molecules on functionalized surfaces, interaction between molecule and substrate, alignment and orientation of molecules, molecular networks 4. **Interfaces:** layered systems, interfacial structures, amorphous boundary phases, alloys 5. **2D materials:** graphene, silicene, germanene, nanotubes 6. **Methods:** X-Ray Photoelectron Spectroscopy (XPS), X-RayPhotoelectron Diffraction (XPD), scanning tunneling microscope (STM), Scanning Tunneling Spectroscopy (STS), Atomic Force Microsopy (AFM), Photoemission Electron Microscopy (PEEM), X-Ray Standing Waves (XSW), electron holography 7. **Techniques:** Ultra-high vacuum, pressure measurements, pumping technique.				
4	**Learning outcome** Students learn modern methods of solid-state physics interdisciplinary for systems of surface and interface physics. In the seminar talks students learn to present complex scientific issues and methodologies in an understandable way. Through discussions, they learn basic principles of scientific exchange and discourse.				
5	**Examination** Module examination: Graded own presentation (30 min + 15 min discussion)				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Prof. C. Westphal		**Faculty in charge** Department of Physics		

Module: Advanced Nonlinear Spectroscopic Methods in Solid State Physics (**PHY628**)				
Degree Program: Physics (M.Sc.)				
Frequency: in SS	**Duration:** 1 semester	**Semester:** 2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	2
2	**Language:** English				
3	**Content** 1. **Linear light-matter interaction:** electric polarization, dielectric tensor, linear optics, linear magneto-optics in magnetic materials (metals and insulators), Drude model, Lorentz model. 2. **Optics of metals:** free-electron model, plasmons 3. **Optics of insulators and semiconductors:** direct and indirect transitions, excitons, 4. **Nonlinear optics:** nonlinear electric polarization, harmonic generation, magnetic generation of harmonics, generation of harmonics from excitons. 5. **Raman spectroscopy:** spontaneous and induced Raman scattering by phonons and magnons. 6. **Time-resolved methods:** pump-probe method, time-resolved SHG and THG, time-resolved Raman spectroscopy.				
4	**Learning outcome** Students gain insight into the physical principles of the optical properties of different classes of materials. The understanding of traditional and modern spectroscopic methods is complemented by direct examples.				
5	**Examination** Module examination: Graded oral examination (30 min)				
6	**Participation Requirements:**				
7	**Module type** Elective module				
8	**Responsible** D. Bossini, Prof. D. Yakovlev		**Faculty in charge** Department of Physics		

Module: Applied Dosimetry (**PHY629**)				
Degree Program: Physics (M.Sc.)				
Frequency: annually in WS	**Duration:** 1 semester	**Semester:** 1st sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	S	3	2
2	**Language:** English				
3	**Content** The course covers the basics of dosimetry and its applications. The course focuses on the aspect of personal dosimetry and its importance in radiation protection of exposed professionals. The seminar will cover the basics of detector physics as well as technological aspects of the application, such as dosimeter requirements and implementation in standardization.				
4	**Learning outcome** Students deepen their knowledge in the field of dosimetry through self-study for their own individual presentations. This lecture also trains skills in scientific research and presentation techniques. Scientific discussion techniques are acquired in the subsequent discussion.				
5	**Examination** Course Credits: Active participation in the discussions following the lectures. Module examination: Graded own technical lecture				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Prof. K. Kröninger		**Faculty in charge** Department of Physics		

Module: Methods of Clinical Research (PHY6210)				
Degree Program: Physics (M.Sc.),				
Frequency: as needed in SS	**Duration:** 1 semester	**Semester:** 2nd sem.	**Credits** 5	**Work load** 150 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	5	3
2	**Language:** English				
3	**Content** Methodological, statistical, legal and ethical aspects in clinical research. 1. **Classification of studies:** observational studies (case-control studies, cross-sectional studies, cohort studies), intervention studies (randomized, controlled, double-blind), phases of clinical trials. 2. **Static discrimination of study groups:** Parametric and non-parametric tests. 3. **Associations of study variables**: Correlation (Pearson, Spearman), regression (univariate, multivariate and logistic). 4. **Risk and prognostic factors**: odds ratio, hazard ratio, absolute risk, relative risk. 5. **Accuracy of diagnostic procedures:** Sensitivity, Specificity, Receiver Operating Curve (ROC), Likelihood Ratio (LR+ and LR-). 6. **Physical endurance:** evaluation of maximal and submaximal exercise tests. 7. **Quality of life:** questionnaires - handling and evaluation. 8. **Legal and ethical aspects:** Good Clinical Practice (GCP), Ethics Committee, Federal Institute for Drugs and Medical Devices (BfArM).				
4	**Learning outcome** Students learn methods used in clinical research. Since medical science involves research on the subject, knowledge of legal and ethical aspects is also acquired. In the exercises, students learn to independently grasp tasks from the field of kinetic research as a problem, solve them and discuss them in the group.				
5	**Examination** Module examination: Graded written exam (120min) or oral exam (30 min), will be given at the beginning of the event announced.				
6	**Participation requirements** Basic knowledge of medical physics				
7	**Module type** Elective module				
8	**Responsible** Dr. G. Weinreich		**Faculty in charge** Department of Physics		

Module: Applications of Machine Learning in Medical Physics **(PHY6211).**				
Degree Program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure** 2 contact hours per week, seminar	
2	**Language:** English	
3	**Content** Machine learning has been increasingly used in many areas of medicine for years and even has the potential to change them completely. Already today, machine learning methods are of great importance, for example, in diagnostics with the help of imaging procedures. There, machine learning methods help physicians to evaluate the highly complex data in order to make a diagnosis more precisely and faster. But machine learning can also be used efficiently in other areas, such as therapy planning, treatment or even in the development of effective drugs, not only to save costs and time, but ultimately to provide patients with the best possible care. In this seminar, you will first get an overview of the diverse applications of machine learning in medicine. In addition, you will scientifically research a selected topic, gain a deeper insight and understanding, and clearly prepare and present it as a lecture. The central focus of these seminar lectures is on the medical-physical applications, less on the technical aspects of machine learning. In addition to the seminar lectures, we prepare short lecture inserts in which we take a closer look at the technical aspects of machine learning in the respective applications and explain them without any necessary prior knowledge.	
4	**Learning outcome** The participants get an overview of current topics in medicine, in which modern machine learning methods are used. You will learn how to research a scientific topic and present it to an audience in a comprehensible lecture. In addition, you will gain insights into how modern machine learning algorithms work.	
5	**Examination** Course Credits: Active participation in the discussions during the seminar hours. Module examination: Graded, independently researched and elaborated seminar presentation.	
6	**Participation requirements** Basic knowledge in medical physics, desirable is the lecture 'Statistical Methods of Data Analysis'.	
7	**Module type** Elective module	
8	**Responsible** Dean of Department of Physics	**Faculty in charge** Department of Physics

Module: Superconductivity (**PHY6212**)				
Degree Program: Physics (M.Sc.)				
Frequency: in SS	**Duration:** 1 semester	**Semester:** 2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	2
2	**Language:** English				
3	**Content** 1. **Fundamental Properties of Superconductors**: vanishing of electrical resistance, perfect diamagnetism, flux quantization, quantum interference 2. **Superconducting materials**: superconducting elements, alloys, MgB_2 , heavy-fermion superconductors, high-Tc cupper oxides, iron-based superconductors, organic superconductors. 3. **Cooper pairing**: Bardeen-Cooper-Schrieffer theory, conventional superconductivity, unconventional superconductivity, energy gap, electromagnetic response 4. **Thermodynamics**: Ginzburg-Landau theory, Type-I superconductors in a magnetic field, Type-II superconductors in a magnetic field, fluctuations above *Tc*, states outside thermodynamic equilibrium 5. **Applications of superconductors** Literature: Reinhold Kleiner and Werner Buckel, *Superconductivity: An Introduction* (Wiley-VCH) Michael Tinkham, *Introduction to Superconductivity* (Dover). James. F. Annett, *Superconductivity, Superfluids and Condensates* (Oxford). Terry R Orlando, Kevin A. Delin, *Foundations of Applied Superconductivity* (Addison-Wesley).				
4	**Learning outcome** The discovery of superconductivity is one of the most prominent scientific achievements over the past century. A significant collection of unexpected and surprising new phenomena was revealed by the study of superconductivity, which greatly enriched our knowledge of quantum mechanics. This course will provide an overview of superconductivity and superconducting materials, based on the preliminary knowledge of solid-state physics and quantum mechanics. Besides the fundamental properties of superconductivity, the lectures will also cover selected topics of the contemporary research.				
5	**Examination** Module examination: Graded oral examination (30 min)				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Prof. Z. Wang		**Faculty in charge** Department of Physics		

Module: Cold atoms and molecules (**PHY6214**)				
Degree Program: Physics (M.Sc.)				
Frequency: Summer term	**Duration:** 1 semester	**Semester:** 2nd semester	**Credits** 6	**Work load** 180 h

1	**Module Structure:**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture with Exercise	L +T	6	2 + 2
2	**Language:** English				
3	**Content** 1) Basic concepts: Atomic structure, Light matter interaction, Bose and Fermi gases. 2) Preparation of quantum gases: Laser cooling, optical and magnetic traps, Evaporative cooling, Detection techniques, Scattering properties. 3) Quantum simulation with ultracold atoms: Optical lattices and Hubbard models, Artificial gauge fields. 4) Basic concepts: Molecular structure, collisions of cold molecules 5) Preparation: Molecular sources and laser cooling 6) Fundamental quantum physics with cold molecules				
4	**Learning outcome** Students learn the foundations of cold atoms and molecules including their preparation and modern research questions, which connect to solid state physics in an interdisciplinary way. In the exercises, the students deepen their understanding by solving related problems and discussing them in the group.				
5	**Examination** Course work: work on the exercises and presentation of the solutions Module exam: graded examination (written or oral depending on number of participants)				
6	**Participation Requirements** Physics IV				
7	**Module type** Elective module				
8	**Responsible** Prof. E. Narevicius Prof. C. Weitenberg		**Faculty in charge** Department of Physics		

Module: Quantum Technologies with Atoms and Photons (**PHY6215**)				
Degree Program: Physics (B.Sc.)				
Frequency: Summer term	**Duration:** 1 semester	**Semester:** 6th semester	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	S	3	2
2	**Language:** English				
3	**Content** Modern topics of quantum technologies with atoms and photons, such as atom interferometers, atomic clocks, atomic qubits in tweezers, dark matter searches, precision spectroscopy of molecules, gravitational wave interferometers, frequency combs, quantum Zeno effect, Hong-Ou Mandel interferometer, Hanbury-Brown Twiss correlations, ghost imaging, and photonic BEC.				
4	**Learning outcome** Students learn key concepts and experiments of quantum technologies with atoms and photons. In the seminar talks, students learn to present complex scientific issues and methodologies in an understandable way. Through discussions, they learn basic principles of scientific exchange and discourse.				
5	**Examination** Module examination: Graded own presentation (30 min + 15 min discussion)				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Prof. E. Narevicius Prof. C. Weitenberg		**Faculty in charge** Department of Physics		

Module: Physics of Life (**BP12**)				
Degree Program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture with tutorial	L+T	6	3 + 1
2	**Language:** English				
3	**Content** 1. Thermodynamics, phase transformations and critical phenomena in biology. Role of fluctuations, Landau-Ginzburg, connection to all other fields. 2. Mechanics of the cell: elasticity of shells, Helfrich theory, wetting, cell adhesion according to Sackmann, budding and line tension. 3. Electrostatics on biopolymers and membranes: Poisson-Boltzmann, Gouy Chapmann, coupling to phase transformations. 4. Polymer theory: Gauss and Flory chain, dynamics (Rousse and Zimm), De Gennes, reptation, semiflexible polymer. 5. Viscoelasticity, theory of biopolymer networks/cytoskeleton. Affine networks, scaling arguments, rubber plateau, dynamics and elasticity. 6. Life at small Reynolds numbers. Microswimmer, reversibility, slender body theory (sperm, bacteria, paramecia, lung,...). 7. Non-linear phenomena. (coupled) nonlinear oscillators (hearing), solitons, application nerves, heart.... 8. Theory of evolution				
4	**Learning outcome** After successful completion of the module • Students will be able to apply physical concepts of hydrodynamics, elasticity theory, thermodynamics/statistics and electrodynamics in an interdisciplinary way to problems in biological and medical physics (especially) on a mesoscopic and macroscopic scale. • Students have learned in the exercises to independently grasp problems from the interdisciplinary subject area of biological physics and physiology as a physical problem, to solve them and to discuss them in the group.				
5	**Examination** Course work: Exercises. Module examination: Graded written exam (120min) or oral exam (30 min), will be announced at the beginning of the event.				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Prof. M. Schneider		**Faculty in charge** Department of Physics		

Module: Advanced Quantum Mechanics (**PHY631**)				
Degree Program: Physics (M.Sc.);				
Frequency: in SS	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 6	**Work load** 180 h

1 Module structure

No.	Element / Course	Type	Credits	Contact hours per week
1	Advanced Quantum Mechanics	L	3	2
2	Exercises in Advanced Quantum Mechanics	T	3	2

2 Language: English

3 Content

(time-dependent) perturbation theory: S-matrix, Fermi's golden rule;
Scattering theory: Lippmann-Schwinger, Born cross section
Path integrals: classical limit, harmonic oscillator;
Relativistic quantum mechanics: Poincare transformers, spinors
Klein-Gordon equation
Dirac equation: covariance, P,T,C, non-relativistic limit, fine structure.
Field quantization, Fock space, photons,
Symmetries, SUSY-QM

Literature:
Schwabl: Quantum Mechanics for Advanced Students,
Peskin, Schroeder: An Introduction to Quantum Field Theory,
L.D. Landau, E.M. Lifshitz: Quantum Mechanics, Vol. III.

4 Learning outcome

Students learn the most important elements of advanced quantum mechanics, as well as the methods for technical handling of questions and calculation of measured quantities. In addition to canonical quantization, the path integral is introduced as an important concept of modern field theory at the harmonic oscillator. Relativistic quantum mechanics is a major focus, here increased emphasis is placed on good mastery and conceptual understanding of the appropriate transformations for objects with spin. Students are introduced to methods as used in current research.
In the exercises, students learn to describe simple physical systems both formally-mathematically and verbally and to present solutions by solving problems independently and discussing them in the group. In doing so, they learn to check their learning success and measure it against that of their fellow students. To encourage teamwork, homework is accepted as group work by up to 3 students.

5 Examination

Course achievement: Homework
Module examination: Graded written exam (120 min)

6 Participation requirements

7 Module type

Elective module

8 Responsible	**Faculty in charge**
Dean of the Department of Physics	Department of Physics

Module: Computational Physics (**PHY632**)				
Degree Program: Physics (M.Sc.)				
Frequency: in SS	**Duration:** 1 semester	**Semester:** 2nd sem.	**Credits** 9	**Work load** 270 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	6	4
	2	Exercise	T	3	2

2 Language: English

3 Content

1. **Basic numerical techniques, e.g.:**
   Numerical differentiation, integration, solution of differential equations. Basic numerical linear algebra problems: systems of linear equations and eigenvalue problems.
2. **Specific numerical techniques of physics, e.g.:**
   Nonlinear optimization in many variables, determination of dominant eigenvalues in high-dimensional spaces, variational methods, solution of coupled ordinary differential equations, molecular dynamics simulations, solution of partial differential equations, Monte Carlo simulations and integrations, solution of stochastic differential equations.
3. **Physical application fields, e.g.:**
   Nonlinear dynamics (Poincaré sections, Lyapunov exponents, attractors, bifurcations). Electrodynamics (potential equation). Optics (diffraction). Quantum mechanics (stationary states, variational methods, ground state calculations, time evolution, scattering problems, Hartree-Fock method). Quantum field theory (lattice QFT, functional integrals). Statistical physics (transfer matrix methods, critical points and critical exponents, simulations of many-body systems with molecular dynamics and classical and quantum Monte Carlo methods, stochastic dynamics). Solid state physics (density functional methods, band structure calculations). Particle physics.

Literature:
Press et al: Numerical Recipes
Schnakenberg: Algorithms in Quantum Theory and Statistical Physics
Thijssen: Computational Physics
Gould-Tobochnik: An Introduction to Computer Simulation Methods.

4 Learning outcome

Students will be able to apply the modern methods of computer-aided theoretical physics and computer simulation to examples from elementary particle and condensed matter physics. This includes recognizing the numerical problem, choosing the appropriate algorithm, and implementing it in a program using projects as homework assignments. Working on the projects in a team promotes teamwork and project management skills, as well as the graphical preparation and presentation of numerical results.

5 Examination

Course achievement: presentation of the exercise projects.
Graded module examination, written or oral (to be announced at the beginning of the course)

6 Participation requirements

7 Module type

Elective module

8	**Responsible** Dean of the Department of Physics	**Faculty in charge** Department of Physics

Module: Theory of Soft and Biological Matter (**PHY633**)				
Degree Program: Physics (M.Sc.)				
Frequency: in SS	**Duration:** 1 semester	**Semester:** 2nd sem.	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours**
	1	Lecture with exercise	L+T	6	3 + 1
2	**Language:** English				

3 Content

Important soft and biological matter systems: colloidal systems, liquid crystals, polymers, fluid interfaces, fluid membranes; cell membrane, DNA, cytoskeleton, proteins, motor proteins, protein filaments.

1. **Statistical physics:**
   virial expansion, phase transitions (MeanField, scale laws).
2. **Molecular interactions:**
   Debye-Hückel theory, van der Waals interaction, DLVO theory, hydrophobic effect, hydrogen bonds, steric interactions.
3. **Polymers:**
   chain models, self-avoidance, polymer solutions, adsorption, rubber elasticity.
4. **Fluid interfaces:**
   surface tension, differential geometry, surfaces of constant curvature, capillary waves, wetting, foams.
5. **Membranes:**
   bending energy, liquid vesicle shapes, thermal fluctuations.
6. **Stochastic dynamics:**
   Brownian motion, diffusion problems, random walk, Markov processes, Langevin equation and Fokker-Planck equation.
7. **Physical and chemical kinetics:**
   thermally activated processes, chemical equilibrium, chemical kinetics, Michaelis-Menten.
8. **Biological physics:**
   molecular motors, filaments, ATP-driven processes.

4 Learning outcome

Students will be able to apply modern methods of theoretical physics (from the fields of statistical physics, mechanics, electrodynamics) to systems of soft matter and biological physics in an interdisciplinary way. In the exercises, the students learn to understand problems from the interdisciplinary subject area of Soft Matter as theoretical-physical problems, to solve them and to discuss them in groups.

5 Examination

Course work: ExercisesModule examination: Graded written exam (120min) or oral exam (30 min), will be announced at the beginning of the course.

6 Participation requirements

7 Module type

Elective module

8	**Responsible** Prof. J. Kierfeld	**Faculty in charge** Department of Physics

Module: General Relativity **(PHY634)**				
Degree Programm: Physics (M.Sc.)				
Frequency: in SS	**Duration:** 1 semester	**Semester:** 2nd sem.	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture with exercise	L+T	6	3 + 1
2	**Language:** English				
3	**Content** Review of special relativity, principles of general relativity, reference frames and equivalence principle, tensor calculus and geometry in curved spaces, gravity and Einstein's field equations, tests of general relativity, Schwarzschild metrics, stellar models, black holes, gravitational waves, outlook on cosmology and quantum gravity. Literature: S.M. Carroll: Spacetime and Geometry: Introduction to General Relativity and others given in the lecture.				
4	**Learning outcome** Students learn how to mathematically understand the space-time structure of curved spaces. They acquire a deeper insight into the physics of gravity and its relation to the structure of spacetime; they learn by example how a theory with measurable consequences emerges from general principles and postulates; they develop and practice the techniques necessary to apply the formalism of general relativity to concrete problems in astrophysics and cosmology.				
5	**Examination** Course work: Homework Module examination: Graded oral examination (30 min) or written examination (120 min), will be announced at the beginning of the course.				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics	**Faculty in charge** Department of Physics			

Module: Advanced Solid State Physics I: Semiconductors and Light-Matter Interaction (PHY635)				
Degree Program: Physics (M.Sc.)				
Frequency: in SS	**Duration:** 1 semester	**Semester:** 2nd sem.	**Credits** 6	**Work load** 150 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	6	4
2	**Language:** English				

3 Content

The lecture covers the most important aspects of the modern physics of crystalline semiconductors and general aspects of the interaction of solids with light. Specifically, the following topics are covered:

1. **Semiconductor Physics:**
   crystal structures, lattice vibrations, electronic band structure of important semiconductor materials, defect states and electrical transport, heterostructures/nanostructures: fabrication and properties, influence of external fields: Stark effect, quantum Hall effect, semiconductor diodes: band diagram and electrical properties
2. **Linear optics:**
   optical properties of dielectrics, semiconductors and heterostructures including semiconductor structures; phonons, plasmons, polarons, excitons, optical Bloch equations; density matrix formalism; strong and ultra-strong light-matter coupling.
3. **Nonlinear optics:**
   nonlinear susceptibility; nonlinear wave equation; phase matching; 3rd and higher order nonlinearities; nonlinear optics of the two-level system.
4. **Fundamentals of quantum optics:**
   quantization of the electromagnetic field; quantum-mechanical states of the light field; coherence.

Literature:
N.W. Ashcroft, N.O. Mermin: "Solid State Physics"
M. Grundmann, “The Physics of Semiconductors: An Introduction Including Nanophysics and Applications”
M. Fox: "Optical Properties of Solids"

4 Learning outcome

The lecture opens a comprehensive view of modern semiconductor physics including the most important heterostructures. It also offers insight into the general optical properties of condensed matter in a broad spectral range from microwave radiation to the ultraviolet. The aim is to develop an understanding in particular of collective electron dynamics, excitations of quasiparticles, nonlinear optical processes and basic features of quantum optics.

5 Examination

Module exam: oral exam (30 min)

6 Participation requirements

7 Module type

Elective module

8	**Responsible** Dean of the Department of Physics	**Faculty in charge** Department of Physics

Module: Accelerator Physics I (**PHY712**)				
Degree Program: Master Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st sem.	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	4	3
	2	Exercises	T	2	1
2	**Language:** English				
3	**Content** 1. **Introduction:** physics basics, history, accelerator types. 2. **Transverse beam dynamics:** magnets, particle optics, transverse phase space 3. **Longitudinal beam dynamics:** high frequency systems, longitudinal phase space 4. **Synchrotron radiation:** properties of synchrotron radiation, radiation damping, wigglers and undulators, synchrotron radiation sources.				
4	**Learning outcome** Students obtain an overview of the physics and technology of particle accelerators that is beneficial not only for a career in accelerator physics, but also for future experimenters at an accelerator. Students learn the essential steps in designing an accelerator or storage ring. They perform beam dynamics calculations as part of exercises, including practice using a scripting language such as Matlab.				
5	**Examination** Study achievements: Successful completion of the exercises on a regular basis, active Participation in the exercises Module examination: Graded oral examination (30 min)				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics		**Faculty in charge** Department of Physics		

Module: Ethics of the Natural Sciences (**PHY7238**)				
Degree Program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st/2 nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	S	3	2
2	**Language:** English				
3	**Content** 1. **Historical positions:** Aristotle (foundation of the discussion in the "Nicomachean Ethics"), Kant (The Categorical Imperative in the Metaphysics of Morals and Critique of Practical Reason), Schopenhauer (Natural Science and Ethics in the "World as Will and Imagination"), Lange (Ethics and Materialism in the "History of Materialism). 2. **Foundations of the current discussion:** Günther Anders (The Antiquity of Man), Hans Jonas ("The Principle of Responsibility"; "Technology, Medicine and Ethics") 3. **Physics in War:** The Farmhall Protocols (Bernstein, "Hilter's Uranium Club"), Navasky, Ethical Function of War ("Report from Iron Mountain"), Robert Jungk ("Brighter than a Thousand Suns"). 4. **Special topics on ethical responsibility in medicine and neuroscience:** e.g. distribution problems concerning medical technology resources (devices, drugs); switching off devices? Prolonging life artificially? Organ transplantation/brain death criterion? Preimplantation diagnostics? Brain doping? Literature: Dieter Sturma, Bert Heinrichs (eds.) (2015) Handbuch Bioethik. Metzler; Biller-Andorno, N., Monteverde, S., Krones, T., Eichinger, T. (eds.) Medizinethik. Springer; Armin Grunwald (ed.): Handbuch Technikethik (2013) Metzler; Stoecker, Ralf, Neuhäuser, Christian, Raters, Marie-Luise (eds.); Handbuch angewandte Ethik (2011) Metzler; Europäische Enzyklopädie zu Philosophie und Wissenschaften, Meiner (1990), further resources: material of the English Ethics Council, DRZE (English Reference Center for Ethics in the Life Sciences), etc.				
4	**Learning outcome** Via self-study on their individual presentation and by attending their peer´s presentations and participating in accompanying discussions, the students acquire a deeper knowledge of the justification of basic positions of ethics and their possibility of application with regard to decision-making problems in natural science or technically induced problems. In addition, the students will acquire the ability to work out the content of specialist texts from the field of philosophy and to identify the core questions relevant to physics or natural sciences and to relate them to the current social situation. The students learn to familiarize themselves with a complex field independently and to present the essential contents in a comprehensive way. They gain knowledge about				

	modern presentation techniques and how to use them. They learn to defend their point of view in a scientific discussion.
5	**Examination** Course achievement: Seminar presentation Module exam: written or oral; will be announced at the beginning of the course.
6	**Participation requirements**
7	**Module type** Elective module
8	**Responsible** Prof. W. Rhode
	Faculty in charge Department of Physics

Module: Soft Matter and Biophysics: Experiment and Theory (**PHY713**)				
Degree Program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Self-study and own presentation	S	3	2
2	**Language:** English				

3 Content

The seminar will consist of student presentations on topics related to soft matter and biophysics:
Experimental methods and theoretical concepts in soft matter and biophysics, e.g.:

1. **Soft Matter:**
   experimental techniques such as small angle X-ray scattering and X-ray reflectivity, theory of colloids (hard spheres), liquid crystals, membranes and vesicles, polymers (DNA), etc.
2. **Biophysics:**
   experimental methods such as X-ray structure analysis and protein crystallization, high-resolution microscopy, theory and simulation of proteins and protein folding, molecular motors, viruses, etc.

4 Learning outcome

Students become familiar with a wide variety of experimental methods and theoretical concepts used in the interdisciplinary field of soft matter and biophysics research. In addition, students also acquire presentation techniques for knowledge transfer and discussion techniques. .

5 Examination

Course achievement: Active participation in the discussions following the lectures.
Module examination: Graded own presentation (30min + 15min discussion).

6 Participation requirements

7 Module type

Elective module

8	**Responsible** Prof. J. Kierfeld, Prof. M. Tolan	**Faculty in charge** Department of Physics

Module: Molecular Simulation of Soft Matter and Biological Materials (**PHY714**)				
Degree program: Physics (M.Sc.)				
Frequency in WS	**Duration** 1 semester	**Semester** 1st/2nd sem.	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture with practical course (exercise)	L+T	6	3+1
2	**Language:** English				

3 Content

1. **Applications in relevant molecular systems:**
   Biological soft matter: proteins and lipid membranes.
   Industrial materials: polymers, metals, surfactants and graphene.

2. **Simulations of molecular systems:**
   Molecular dynamics: underlying approximations, efficient
   algorithms, integration of Newton's equations of motion, time reversibility, ensembles (barostats and thermostats).
   Monte Carlo simulations and heuristic sampling methods (e.g., Evolutionary algorithms)
   Coarse-graining and mesoscopic simulation methods.

3. **Free energy calculations:** Reaction coordinates, free energy perturbation, thermodynamic
   integration, umbrella sampling, strings methods.

4. **Non-equilibrium thermodynamics**:
   Jarzynski Equation and Crooks Theorem

4 Learning outcome

Students learn to apply modern compter methods (from the fields of statistical physics, mechanics) to molecular systems of soft matter and biological physics in an interdisciplinary manner. The power and relevance of these methods are demonstrated using exciting examples from the scientific literature. In the exercises, students learn to translate problems from the interdisciplinary subject area of soft matter into a computational-physical problem, to address them and to discuss them in the group.

5 Coursework and examination requirements

Course work: Practical exercises
Module exam: Graded written exam (120min) or oral exam (30 min), will be announced at the beginning of the course.

6 Participation requirements

7 Module type

Elective module

9	**Responsible** Prof. H. J. Risselada	**Faculty in charge** Department of Physics

Module: Current Problems in the Field of Synchrotron Radiation Utilization and Tunneling Microscopy (**PHY722)**				
Dregree Programm: Physics (M.Sc.)				
Frequency: every semester	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Self-study and own presentation	S	3	2
2	**Language:** English				
3	**Content** The seminar will consist of presentations of current research in the areas of synchrotron radiation utilization and tunneling microscopy. Recent measurements from ongoing work and publications will be presented. Current measurements with synchrotron radiation and tunneling microscopy will be presented and discussed. Recent publications from the fields will be presented. Literature: will be announced/provided in the seminar for the respective topics.				
4	**Learning outcome** Students learn about the state of the art in research in the areas of utilzation of synchrotron radiation for the study of surfaces and interfaces as well as from the field of tunneling microscopy and spectroscopy and cluster physics.				
5	**Examination** Course achievement: Active participation in the discussions following the lectures. Module examination: Graded own presentation on a topic from current research.				
6	**Participation requirements** In-depth knowledge of solid state physics and surface physics				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics		**Faculty in charge** Department of Physics		

Module: Key Experiments in Particle Physics (**PHY723**)				
Degree Program: Physics (M.Sc.)				
Frequency: annual	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 4	**Work load** 120 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	S	4	2
2	**Language:** English				
3	**Content** Key experiments in particle physics, in particular fundamental discoveries and the development of key experimental technologies. These include the Wu experiment, the discovery of the Higgs boson, and the development of semiconductor detectors for particle physics. The experiments are placed in their historical context and their significance for particle physics is elaborated.				
4	**Learning outcome** Students deepen their knowledge in the field of particle physics through a self-study for their own lecture. This lecture also trains skills in scientific research and presentation techniques. Scientific discussion and writing techniques are acquired in the subsequent discussion and by preparing a written summary on the entire course content.				
5	**Examination** Course achievement: Active participation in the discussions following the lectures. Module examination: Graded own lecture and preparation of a written report. Summary of the entire course.				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics		**Faculty in charge** Department of Physics		

Module: Measurement Methods in Surface Physics (**PHY724**)				
Degree Program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st sem.	**Credits** 6	**Work load** 180 h

1 Module structure

No.	Element / Course	Type	Credits	Contact hours per week
1	Lecture with exercise	L + T	6	3 + 1

2 Language: English

3 Content

The lecture consists of a theoretical part with reference to and examples from practice: Basic concepts of surface physics; experimental prerequisites; introduction to the most important measurement methods; description and nomenclature in surface physics; electronic and structural properties of surfaces; interactions at surfaces; surface states; atoms and molecules on surfaces, organic molecular films, insight into nanotechnology: nanostructures, micro and nano fabrication of structures, micro and nano applications.

Literature:
Henzler/Göpel, Surface Physics of the Solid State,
F. Bechstedt/P. Herzog, Principles of Surface Physics,
K. Kopitzki Introduction to Solid State Physics, W. Mönch, Semiconductor Surfaces and Interfaces;
S. Morita/R.Wiesendanger/E.Meyer (Eds.), Noncontact Atomic Force Microscopy;
W. Schattke/M.A. Van Hove (Eds.), Solid-State Photoemission and Related Methods;
B. Bushan (Ed.), Springer Handbook of Nanotechnology; D.P. Woodruff/T.A. Delchar, Modern Techniques of Surface Science-Second Editon.

4 Learning outcome

The students know the basics of surface physics and surface-specific techniques: these are necessary prerequisites and allow early experimental approaches. They master the most important measurement methods used in surface physics from the theoretical side. The students know the respective strengths and limitations of the methods, and they have an overview of the respective advantages and disadvantages of the techniques used.
The students make the necessary distinctions between volume and surface-specific techniques for the targeted characterization of materials; they explain their properties using examples. In addition, they know the most important interaction mechanisms of atoms and molecules with surfaces. They use this basis for subsequent insights into applications in nanotechnology.

5 Examination

Course Credits: Homework.
Module examination: Graded oral examination (30 min)

6 Participation requirements

7 Module type

Elective module

8 Responsible	**Faculty in charge**
Prof. C. Westphal	Department of Physics

Module: Accelerator Physics and Synchrotron Radiation: Applications in Solid State Physics (**PHY726**)				
Degree Program: Physics (M.Sc.)				
Frequency: every semester	**Duration:** 1 semester	**Semester:** 1st -2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Self-study and own presentation	S	3	2

2	**Language:** English
3	**Content** The seminar consists of subfields of active research with storage rings and with synchrotron radiation: Current problems of generation and current applications with synchrotron radiation; methods of solid state physics for research with synchrotron light in the soft to hard X-ray range; electronic and structural properties of surfaces Literature: will be announced/provided in the seminar for the respective topics.
4	**Learning outcome** The students know current problems in the generation of synchrotron radiation. For this purpose, they discuss modern methods for the characterization of accelerators. Today, synchrotron radiation is used to describe surfaces in many fields, for example physics, chemistry and biology. These methods connect disciplines in modern research. Through the joint seminar from the field of synchrotron radiation generation and the field of applications, the ability to work in a team is promoted. The students have modern methods for scientific research and the latest presentation techniques, which they deepen with their own contribution. Furthermore, they are able to weigh different methods and techniques of the use of synchrotron radiation in research for surface and volume specific analysis contextually against each other and discuss them problem-oriented.
5	**Examination** Course Credits: Active participation in the discussions following the lectures. Module examination: Graded own presentation on a topic from current research.
6	**Participation requirements** Recommended: accelerator physics
7	**Module type** Elective module

8	**Responsible** Dean of the Department of Physics	**Faculty in charge** Department of Physics

Module: Atomically Resolved Surface and Interface Analysis (**PHY727**)				
Degree programm: Physics (M.Sc.)				
Frequency: in SS	**Duration:** 1 semester	**Semester:** 1st-3rd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	2
2	**Language:** English				
3	**Content** Introduction: basic properties of surfaces / interfaces; methods for real space imaging (scanning tunneling microscopy, atomic force microscopy, etc.); diffraction with electron and atomic beams at surfaces; investigation of nanostructures at surfaces; X-ray and neutron scattering (basics); X-ray reflectivity at surfaces and interfaces: Theory and examples.				
4	**Learning outcome** Students will learn different methods to investigate the nanoscopic structure of surfaces and interfaces, up to methods with atomic resolution. In particular, methods for real space imaging are compared with diffraction methods. The presentation of the basic mechanisms is complemented with many examples from current research. Fields of application such as nanotechnology will be highlighted.				
5	**Examinations** Module examination: Graded oral module examination (30 min) or short written test.				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics		**Faculty in charge** Department of Physics		

Module: Solid State Spectroscopy (**PHY728**)				
Degree Program: Physics (M.Sc.)				
Frequency: every semester	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Self-study and own presentation	S	3	2
2	**Language:** English				
3	**Content** The seminar deals with subfields of active research, mainly magnetic resonance, but also dielectric and optical spectroscopy of solids: Novel methodological developments in nuclear and electron spin resonance and related spectroscopy techniques and their application to quantum physics, materials science, and medical physics issues. Literature: will be announced / provided in the seminar on the respective topics.				
4	**Learning outcome** Students have an overview of some essential spectroscopic methods for the study of both hard and soft matter. Accompanied by the lecturers, the students get to know a special field of research in more detail by means of the original literature and are able to prepare it in a structured way for the presentation in a presentation. Through the mandatory regular participation, you will also have an overview of other current developments in the field of solid state spectroscopy. The mandatory own presentation trains competences in the field of scientific research and presentation techniques.				
5	**Examination** Course Credits: Active participation in the discussions following the lectures. Module examination: Graded own presentation on a topic from current research.				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics			**Faculty in charge** Department of Physics	

Module: Lasers - Types and Applications (**PHY729**)				
Degree Program: Physics (M.Sc.)				
Frequency: annual	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Self-study and own presentation	S	3	2
2	**Language:** English				
3	**Content** The seminar consists of sections on the fundamentals of laser processes and on active research with lasers: Laser processes, laser types (solid-state, gas, semiconductor, electron lasers, etc.), generation and application of ultrashort laser pulses, generation and application of extremely narrowband lasers, high-power lasers, lasers for communication and message transmission, lasers in medicine. Literature: will be announced/provided in the seminar for the respective topics.				
4	**Learning outcome** Students learn about current problems in the production and use of lasers. The obligatory individual presentation trains competences in the field of scientific literature research and presentation techniques. Different approaches and working methods provide an overview of research with laser radiation.				
5	**Examination** Course Credits: Active participation in the discussions following the lectures. Module examination: Graded own presentation on a topic from current research.				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics	**Faculty in charge** Department of Physics			

Module: Particle and Astroparticle Physics (**PHY7210**)				
Degree Program: Physics (M.Sc.)				
Frequency: every semester	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Self-study and own presentation	S	3	2
2	**Language:** English				
3	**Content** The seminar will cover subfields of research in experimental particle and astroparticle physics and related fields such as cosmology and nuclear physics. Literature: will be announced or provided in the seminar on the respective topics.				
4	**Learning outcome** Students will deepen their knowledge in the field of the seminar through self-study for their individual presentations. These talks also train skills in scientific literature research and presentation techniques. In the subsequent discussion, scientific discussion techniques are acquired.				
5	**Examination** Course Credits: Active participation in the discussions following the lectures. Module examination: Graded own presentation.				
6	**Participation requirements**				
7	**Module type** Elective module i				
8	**Responsible** Dean of the Department of Physics		**Faculty in charge** Department of Physics		

Module: Neutrino and Gamma Astronomy (**PHY7211**)				
Degree Program: Physics (M.Sc.)				
Frequency: every semester	**Duration:** 1 semester	**Semester:** 1st/2nd Sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Self-study and own presentation	S	3	2
2	**Language:** English				
3	**Content** The seminar will cover subfields of research in the fields of neutrino and gamma astronomy and connecting fields such as cosmology and particle physics. Methods of analyzing the large amounts of data generated in these fields may also be covered. Literature: will be announced or provided in the seminar on the respective topics.				
4	**Learning outcome** Students deepen their knowledge in the field of the seminar through self-study on your own lecture. This lecture also trains skills in the area of scientific literature research and presentation techniques. Scientific discussion techniques are acquired in the subsequent discussion.				
5	**Examination** Course Credits: Active participation in the discussions following the lectures. Module examination: Graded own presentation.				
6	**Participation requirements** Recommended: astroparticle physics.				
7	**Module type** Elective module				
8	**Responsible** Prof. W. Rhode		**Faculty in charge** Department of Physics		

Module: Particle Physical Aspects of Cosmic Rays (**PHY7212**)				
Degree Program: Physics (M.Sc.)				
Frequency: As needed	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Self-study and own presentation	S	3	2
2	**Language:** English				
3	**Content** In the seminar subareas of research in the field of cosmic rays and related fields are treated. Special attention is given to particle physics aspects. Literature: will be announced or provided in the seminar on the respective topics.				
4	**Learning outcome** Students deepen their knowledge in the field of the seminar through self-study on your own lecture. This lecture also trains skills in the area of scientific literature research and presentation techniques. In the subsequent discussion scientific discussion techniques acquired.				
5	**Examination** Course Credits: Active participation in the discussions following the lectures. Module examination: Graded own presentation.				
6	**Participation requirements** Recommended: astroparticle physics				
7	**Module type** Elective module				
8	**Responsible** Prof. W. Rhode		**Faculty in charge** Department of Physics		

Module: Modern Optics (**PHY7213**)				
Degree Program: Physics (M.Sc.)				
Frequency: in SS	**Duration:** 1 semester	**Semester:** 1st-3rd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	S	3	2
2	**Language:** English				
3	**Content** Novel methodological developments for light field control and modern optical techniques for spectroscopy and imaging and their application in basic research, materials science and medical physics. Literature: will be announced/provided in the seminar for the respective topics.				
4	**Learning outcome** Students learn about current optical methods and applications. The students work out a delimited research topic on the basis of the original literature and prepare it for a presentation. The prescribed own presentation trains competences in the field of scientific literature research and presentation techniques. In the subsequent discussion, students learn scientific discussion techniques. The breadth of topics gives students an overview of the use of optical processes in both research and industrial applications.				
5	**Examination** Course Credits: Active participation in the discussions following the lectures. Module examination: Graded own presentation on a topic from current research.				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics		**Faculty in charge** Department of Physics		

Module: Quantum Optics (PHY7214)				
Degree Program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st-3rd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	2
2	**Language:** English				
3	**Content** Quantization of the light field, discrete variables, photon statistics, correlation functions and Fock states, continuous variables, Wigner functions and squeezed light, light-matter interaction, rotating-wave approximation, cavity quantum electrodynamics, Jaynes-Cummings model and Rabios oscillations, Mollow triplet and resonance fluorescence, weak measurements, entanglement, causality, and the delayed choice quantum eraser. Literature: Mandel/Wolf: Optical Coherence and Quantum Optics, Scully/Zubairy: Quantum Optics, Walls/Milburn: Quantum Optics, W. Schleich: Quantum Optics in Phase Space.				
4	**Learning outcome** Students learn fundamental effects of quantum optics and the adequate theoretical formalism to describe them. This enables the students to understand original papers independently and provides them with the necessary competence to successfully write theses in the field of experimental quantum optics as well as in the field of the theory of light-matter interaction.				
5	**Examinations** Module examination: Graded oral module examination (30 min).				
6	**Participation Requirements:**				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics		**Faculty in charge** Department of Physics		

Module: Reading course on particle physics (**PHY7215**)				
Degree Program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	S	3	2
2	**Language:** English				
3	**Content** The seminar will focus on special topics in particle physics, e.g. dark matter, neutrinos or top quark physics.				
4	**Learning outcome** The participants read given publications in preparation for the seminar and have to search for further literature on their own. The publications will be discussed in detail during the seminar and placed in the context of particle physics. Thus, the reading of scientific papers shall be practiced and discussion techniques shall be learned. Furthermore, the participants will prepare summaries of the discussion, which are based on the concept of conference negotiations.				
5	**Examination** Course credits: written summaries of discussions. Module examination: Graded oral examination.				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics		**Faculty in charge** Department of Physics		

Module: Radio Astronomy (**PHY7217**)				
Degree Program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Self-study and own presentation	S	3	2
2	**Language:** English				
3	**Content** In the seminar, subareas of research in the field of radio astronomy are covered. Literature: will be announced or provided in the seminar on the respective topics.				
4	**Learning outcome** Students deepen their knowledge in the field of the seminar through self-study on your own lecture. This lecture also trains skills in the area of scientific literature research and presentation techniques. In the subsequent discussion scientific discussion techniques acquired.				
5	**Examination** Course Credits: Active participation in the discussions following the lectures. Module examination: Graded own presentation.				
6	**Participation requirements** Recommended: astroparticle physics.				
7	**Module type** Elective module				
8	**Responsible** Prof. W. Rhode	**Faculty in charge** Department of Physics			

Module: Cosmic Rays (**PHY7218**)				
Degree Program: Physics (M.Sc.)				
Frequency: as needed	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Self-study and own presentation	S	3	2
2	**Language:** English				
3	**Content** The seminar will cover subfields of research in the field of cosmic rays and related fields. Literature: will be announced or provided in the seminar on the respective topics.				
4	**Learning outcome** Students deepen their knowledge in the field of the seminar through self-study on your own lecture. This lecture also trains skills in the area of scientific literature research and presentation techniques. Scientific discussion techniques are acquired in the subsequent discussion.				
5	**Examination** Course Credits: Active participation in the discussions following the lectures. Module examination: Graded own presentation.				
6	**Participation requirements** Recommended: astroparticle physics.				
7	**Module type** Elective module				
8	**Responsible** Prof. W. Rhode		**Faculty in charge** Department of Physics		

Module: Physical-Chemical Analytics 1a, Applied Spectrometry (**PHY7219a**)				
Degree program: Physics (M.Sc.)				
Frequency: as needed	**Duration:** 1 semester	**Semester:** from 1st sem.	**Credits:** 3	**Work load:** 90 h

1 Module structure

No.	Element / Course	Type	Credits	Contact hours per week
1	Lecture	L	3	2

2 Language: English

3 Content

Methods of modern analytics (with in-depth study of spectroscopic methods):

1. **Elemental analysis:**
   atomic absorption spectrometry; atomic emission analysis; X-ray fluorescence analysis; elemental mass spectroscopy.
2. **Molecular analysis:**
   infrared and Raman spectroscopy; NMR spectroscopy; Molecular mass spectrometry, solid state and surface analysis: microbeam analysis with photons, electrons and ions; structural analysis.

4 Learning outcome

Students gain an overview of the physical principles of modern analytics and are able to independently develop strategies for solving different analytical problems. They know the most important methods, their performance limits and areas of application. They have acquired the ability to select the most suitable methods in the various fields of application and to critically evaluate their results.

5 Examination

Module examination: Graded oral examination

6 Participation requirements

7 Module type

Elective module

8 Responsible	**Faculty in charge**
PD J. Franzke	Department of Physics

Module: Physical-Chemical Analytics 2a, Applied Plasma Physics (**PHY7220a**)				
Degree program: Physics (M.Sc.)				
Frequency: 2-year	**Duration:** 1 semester	**Semester:** from 1st sem.	**Credits:** 3	**Work load:** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	2
2	**Language:** English				
3	**Content** 1. **Methods of modern analytics** (with in-depth study of spectroscopic methods): Physics of pulsed and continuous plasmas, plasma diagnostics, low and high pressure plasmas; 2. **Analytical plasmas:** glow discharges, arcs, inductively coupled plasmas, dielectric impeded discharges, laser generated plasmas; 3. **Plasma Emission Spectrometry and Plasma Mass Spectrometry**				
4	**Learning outcome** Students gain an overview of the physical principles of modern analytics and are able to independently develop strategies for solving different analytical problems. They know the most important methods, their performance limits and areas of application. They have acquired the ability to select the most suitable methods in the various fields of application and to critically evaluate their results.				
5	**Examination** Module examination: Graded oral examination				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** PD J. Franzke		**Faculty in charge** Department of Physics		

Module: Physical-Chemical Analytics 3a, Applied Laser Spectrometry (**PHY7221a**)				
Degree program: Physics (M.Sc.)				
Frequency: 2-year	**Duration:** 1 semester	**Semester:** from 1st sem.	**Credits:** 3	**Work load:** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	2
2	**Language:** English				
3	**Content** Methods of modern analytics (with in-depth study of spectroscopic methods): The laser as a spectroscopic instrument; absorption, fluorescence and Ionization spectrometry with lasers; high resolution spectrometry with lasers; optoacoustic and optothermal methods; surface plasmon resonance spectrometry; surface enhanced Raman spectroscopy; laser ionization mass spectrometry (RIMS, MALDI, etc.).				
4	**Learning outcome** Students gain an overview of the physical principles of modern analytics and are able to independently develop strategies for solving different analytical problems. They know the most important methods, their performance limits and areas of application. They have acquired the ability to select the most suitable methods in the different areas of application and to critically evaluate their results.				
5	**Examination** Module examination: Graded oral examination				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** PD J. Franzke		**Faculty in charge** Department of Physics		

Module: Physical-Chemical Analytics 1b, Applied Spectrometry (**PHY7219b**)				
Degree program: Physics (M.Sc.)				
Frequency: 2-year	**Duration:** 1 semester	**Semester:** from 1st sem.	**Credits:** 5	**Work load:** 150 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	2
	2	Lab Experiment	P	2	

2 Language: English

3 Content

Methods of modern analytics (with in-depth study of spectroscopic methods):

1. **Elemental analysis:**
   atomic absorption spectrometry; atomic emission analysis; X-ray fluorescence analysis; elemental mass spectroscopy.
2. **Molecular analysis:**
   infrared and Raman spectroscopy; NMR spectroscopy;
3. **Molecular mass spectrometry, solid state and surface analysis:**
   microbeam analysis with photons, electrons and ions; structural analysis

Lab experiment: absorption spectrometry, emission spectrometry

4 Learning outcome

Students gain an overview of the physical principles of modern analytics and are able to independently develop strategies for solving different analytical problems. They know the most important methods, their performance limits and areas of application. They have acquired the ability to select the most suitable methods in the various fields of application and to critically evaluate their results.

5 Examination

Module examination: Graded oral examination

6 Participation requirements

7 Module type

Elective module

Of the modules "Physical-Chemical Analysis 1b and 2b" **only one** can be chosen. The associated a-module can then no longer be selected because Part b includes Part a.

8	**Responsible**	**Faculty in charge**
	PD J. Franzke	Department of Physics

Module: Physical-Chemical Analytics 2b, Applied Plasma Physics (**PHY7220b**)				
Degree program: Physics (M.Sc.)				
Frequency: 2-year	**Duration:** 1 semester	**Semester:** From 1st sem.	**Credits:** 3 + 2	**Work load:** 150 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture Applied Plasma Physics	L	3	2
	2	Lab Experiment	P	2	
2	**Language**: English				
3	**Content** Methods of modern analytics (with in-depth study of spectroscopic methods): physics of pulsed and continuous plasmas, plasma diagnostics, low and High pressure plasmas, analytical plasmas: glow discharges, arcs, inductively coupled plasmas, dielectric impeded discharges, laser generated plasmas; Plasma Emission Spectrometry and Plasma Mass Spectrometry Lab experiment: absorption spectrometry, emission spectrometry				
4	**Learning outcome** Students gain an overview of the physical principles of modern analytics and are able to independently develop strategies for solving different analytical problems. They know the most important methods, their performance limits and areas of application. They have acquired the ability to select the most suitable methods in the various fields of application and to critically evaluate their results.				
5	**Examination** Module examination: Graded oral examination				
6	**Participation requirements**				
7	**Module type** Elective module **Only one of** the modules "Physical-Chemical Analysis 1b and 2b" can be selected. The associated a-module can then no longer be selected because Part b includes Part a.				
8	**Responsible** PD J. Franzke	**Faculty in charge** Department of Physics			

Modules: Magnetism II (**PHY7222a**)				
Degree program: Physics (M.Sc.)				
Frequency As needed	**Duration** 1 semester	**Semester** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	2
2	**Language:** English				
3	**Content** The lecture covers advanced topics in magnetism. In particular, focus will be put on the three following themes: **Hybrid molecular interfaces for optoelectronics and spin-electronics**: basic concepts of surface science, physisorption and chemisorption of molecules on metallic surfaces, the concept of a spinterface, active molecular spinterfaces. **Rashba systems:** two-dimensional electron systems, Rashba splitting, Rashba systems for spintronics applications. **Topological insulators:** topology in material science, topological insulators. The seminar focuses on groundbreaking experiments related to the fields of research discussed in the lecture.				
4	**Learning outcome** This course starts from the fundamentals on magnetism that are discussed in the magnetism lecture and applies them to modern topics in condensed matter physics. The students will acquire a deep insight on different topics that are currently in the focus of intense research in the magnetism community. This course is basically intended as a preparatory course for students who want to pursue a PhD in a topic related to magnetism, surface science and solid state physics. In the seminar, the students acquire skills for the critical reading of the literature and improve their presentation techniques.				
5	**Examination** Module examination (lecture) or module component examinations (lecture and seminar)				
6	**Coursework and examination requirements** Course work: Active participation in the lecture and the seminar. Examination: Graded oral examination and, if applicable, graded presentation of about 30 minutes in the seminar.				
7	**Participation requirements** Recommended: magnetism				
8	**Module type** Elective module				
9	**Responsible** Prof. M. Cinchetti		**Faculty in charge** Department of Physics		

Modules: Magnetism II (**PHY7222b**)				
Degree program: Physics (M.Sc.)				
Frequency As needed	**Duration** 1 semester	**Semester** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	S	3	2
2	**Language:** English				
3	**Content** The lecture covers advanced topics in magnetism. In particular, focus will be put on the three following themes: **Hybrid molecular interfaces for optoelectronics and spin-electronics**: basic concepts of surface science, physisorption and chemisorption of molecules on metallic surfaces, the concept of a spinterface, active molecular spinterfaces. **Rashba systems:** two-dimensional electron systems, Rashba splitting, Rashba systems for spintronics applications. **Topological insulators:** topology in material science, topological insulators. The seminar focuses on groundbreaking experiments related to the fields of research discussed in the lecture.				
4	**Learning outcome** This course starts from the fundamentals on magnetism that are discussed in the magnetism lecture and applies them to modern topics in condensed matter physics. The students will acquire a deep insight on different topics that are currently in the focus of intense research in the magnetism community. This course is basically intended as a preparatory course for students who want to pursue a PhD in a topic related to magnetism, surface science and solid state physics. In the seminar, the students acquire skills for the critical reading of the literature and improve their presentation techniques.				
5	**Examination** Module examination (lecture) or module component examinations (lecture and seminar)				
6	**Coursework and examination requirements** Course work: Active participation in the lecture and the seminar. Examination: Graded oral examination and, if applicable, graded presentation of about 30 minutes in the seminar.				
7	**Participation requirements** Recommended: magnetism				
8	**Module type** Elective module				
9	**Responsible** Prof. M. Cinchetti		**Faculty in charge** Department of Physics		

Module: Information Technology of the Future (**PHY7224**)				
Degree Program: Physics (M.Sc.)				
Frequency: As needed	**Duration:** 1 semester	**Semester:** 1^{st}-3^{rd} sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours**
	1	Seminar	S	3	2
2	**Language:** English				
3	**Content** The field of spin electronics arose from the idea of using the spin and charge degrees of freedom of electrons together in electronic devices. Due to the continuous development in the miniaturization of magnetic structures, surprising effects were found at the end of the 1980s concerning the interaction of the "static magnetic" and the "dynamic electric" properties of solids. Such "magnetoresistive" effects are the basis of today's data storage and processing. In the seminar we will cover the most important concepts of spin electronics, and from there discuss new concepts for data storage and processing that have emerged from the research fields of spin orbitronics, optomagnetism, and oxide electronics.				
4	**Learning outcome** The seminar introduces to the physical principles and electronic functionalities of magnetic phenomena in the field of information technology. Fundamental aspects as well as recent developments in the field of spin electronics, orbitonics and oxitronics are discussed. Furthermore, independent research and appropriate presentation techniques will be trained.				
5	**Examination** Course achievement: Active participation in the discussions following the lectures. Module examination: Graded own presentation on a seminar topic (30-45min + discussion).				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Prof. M. Cinchetti		**Faculty in charge** Department of Physics		

Module: Tandem Projects in Particle Physics (**PHY7225**)				
Degree Program: Physics (M.Sc.)				
Frequency: annual	**Duration:** 2 semesters	**Semester:** 1st/2nd sem.	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Project work	P	3	2
	2	Summer School / Block Course	L	3	2
2	**Language:** English				
3	**Content** In the first part of the course, the participants work on a scientific project. The work is done in groups of two to three students from other universities, e.g. Bologna or Clermont. The topics are taken from particle physics. In the second part of the course, the participants attend a one-week international summer school (BCD Summer School in Cargese/Corsica). There, the participants get an overview of fundamental and current topics in particle physics and present their project work in a lecture.				
4	**Learning outcome** Students will learn in-depth aspects of particle physics in the subject area of the course. The focus is on cross-university and cross-national work in small groups. Presentation and discussion techniques will also be trained.				
5	**Examination** Course achievement: Project presentation. Module examination: Graded final report				
6	**Participation Requirements:**				
7	**Module type** Elective module				
8	**Responsible** Prof. K. Kröninger		**Faculty in charge** Department of Physics		

Module: Applied Physics in Clinical Medicine (**PHY7226**)				
Degree Program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	S	3	2
2	**Language:** English				
3	**Content** 1. Physics as a duty for the physician (radiation protection, Medical Devices Act) 2. Technical devices in diagnostics and therapy 3. Brain, eye, ear 4. Neck 5. Lung 6. Heart 7. Visceral surgery I (esophagus, gastrointestinal) 8. Visceral surgery II (liver, gall bladder, pancreas) 9. Trauma surgery 10. Orthopedics 11. Angiology				
4	**Learning outcome** Basic knowledge of applied physics in the clinical medicine according to the course content. The seminars are structured so that first the anatomy and physiology, the pathophysiology and then the typical diseases are discussed and to what extent physics is applied in diagnostics and therapy. When possible, particular reference is made to the possible field of activity of the medical physicist.				
5	**Examination** Written or oral module final examination: the requirements. will be announced by the instructor at the beginning of the course.				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Dr. A. Schilling		**Faculty in charge** Department of Physics		

Module: The Search for New Particles, Dark Matter & Co. (**PHY7227**)				
Degree Program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	S	3	2
2	**Language:** English				
3	**Content** The content of the seminar is the search for new particles, such as dark matter candidates, new quarks and leptons, or new gauge bosons. The focus is on current experimental approaches and results.				
4	**Learning outcome** Students deepen their knowledge in the field of the seminar through self-study on their own presentation. This lecture also trains competencies in scientific literature research and presentation techniques. In the subsequent discussion, scientific discussion techniques are acquired.				
5	**Examination** Course Credits: Active participation in the discussions following the lectures. Module examination: Graded own presentation.				
6	**Participation Requirements**				
7	**Module type** Elective module				
8	**Responsible** Prof. K. Kröninger		**Faculty in charge** Department of Physics		

Module: Superconducting Technology applied to particle accelerators (**PHY7228**)				
Degree Program: Physics (M.Sc.)				
Frequency: In WS	**Duration:** 2 weeks	**Semester:** 1st sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	S	3	Block course
2	**Language:** English				
3	**Content** Along the seminar the principles and the application of superconducting radio frequency (SRF) technologies to the operation particle accelerators will be studied. To this end the key topics will be introduced by means of a lecture (superconductivity, SRF cavities, RF losses, limits of normal conducting cavities vs superconducting systems, loss mechanisms, ...). In addition, the students will complement the lectures with their own research on a related proposed topic to be presented by the end of the seminar. In order to prepare this presentation additional material such as scientific papers or presentations will be provided.				
4	**Learning outcome** The participants will carry out independent research on the suggested topic in order to complete the material taught during the seminar. This work will be presented to the other participants and actively discussed.				
5	**Examination** Course achievements: Active participation in the discussions following the lectures. Module examination: Graded own presentation.				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Prof. A. Velez Saiz		**Faculty in charge** Department of Physics		

Module: Terahertz Dynamics of Condensed Matter (**PHY7229**)				
Degree Program: Physics (M.Sc.)				
Frequency: Every semester	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Self-study and own presentation	S	3	2
2	**Language:** English				
3	**Content** This seminar will constitute of presentations given by the participants on selected topics in the field of Terahertz dynamics in condensed matter. Both experimental methods and theoretical concepts will be covered for measuring and understanding the linear and nonlinear Terahertz responses of various systems. Examples include: • **Terahertz spectroscopy**: Sources for THz generation, time-resolved THz spectroscopy, two-dimensional THz spectroscopy, combinations with other spectroscopic or microscopic techniques etc. • **Solid-state systems:** semiconductors, magnetic materials, superconductors, topological materials, THz cavity quantum electrodynamical structures, etc.				
4	**Learning outcome** The students will learn different experimental approaches to investigating the dynamics of selected condensed-matter systems in the THz frequency range, as well as the theoretical principles governing the observed THz dynamics. This seminar is aimed to provide a comprehensive introduction to the frontiers of THz science, and serves as a preparatory course for students who are interested in pursuing a PhD in a related research topic or curious about this very active research field.				
5	**Examination** Performance: active participation within the seminar presentations and discussions. Module examination: Graded own presentation (30min + 15min discussion)				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Prof. C. Lange, Prof. Z. Wang		**Faculty in charge** Department of Physics		

Module: Quantum Technologies (**PHY7230**)				
Degree Program: Physics (M.Sc.)				
Frequency: as needed in SS and WS	**Duration:** 1 semester	**Semester:** 1st-4th sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	S	3	2
2	**Language:** English				
3	**Content** The seminar covers all subfields of quantum technologies, in particular quantum sensing, quantum metrology, quantum simulation, quantum computing, quantum information processing, quantum communication and quantum cryptography. For this purpose, a current or fundamental publication is to be worked on by each student and presented to the entire group in a didactically prepared manner and then discussed in detail within the group. Publications that represent a significant technological, theoretical, or even methodological advance in one of these subfields are the focus of the seminar.				
4	**Learning outcome** In the seminar, students acquire the core competencies for the successful acquisition of results from the relevant specialist literature. A key point here is the independent development of the content of a technical article. This also includes the learning of efficient literature research and the didactic preparation of the material in order to be able to present it in a lecture. In their role as listeners, students also learn how to efficiently understand the core information of a compact lecture and how to deepen their understanding of the material by asking specific further questions. In addition, students learn about the professional status quo in the field of quantum technologies.				
5	**Examination** Course Credits: Active participation in the discussions following the lectures. Module examination: Graded own presentation at presentation of the publication.				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Prof. M. Aßmann		**Faculty in charge** Department of Physics		

Module: Dynamics of Open Quantum Systems (**PHY7231**)				
Degree Program: Physics (M.Sc.)				
Frequency: as needed in SS and WS	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 5	**Work load** 150 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture with exercise	L+T	5	2 + 1
2	**Language:** English				
3	**Content** **Lecture:** Coupling of optical light fields to an external reservoir, time evolution of first and higher order correlation functions. Master equations for light fields in the absence or presence of light-matter interaction. The birth-death model of the laser, the quantum regression theorem, quantum trajectories, quantum jump formalism, weak measurements. **Practice:** Numerical treatment of selected open systems problems, e.g., coupling of a coherent state to a thermal bath, stochastic ODEs, quantum process tomography.				
4	**Learning outcome** Students learn theoretical methods for the treatment of open systems and can apply these methods to problems from the field of optics. In the exercises, the students learn the concrete implementation of these approaches and develop an understanding of how to grasp open optical systems as a problem and how to adequately describe and solve them. Both the physical concepts and the concrete implementation of solution approaches will be discussed in the group.				
5	**Examination** Module examination: oral module examination (30 Minutes)				
6	**Participation requirements** Knowledge of higher quantum mechanics desirable e.g. by completing the module PHY631 "Advanced Quantum Mechanics".				
7	**Module type** Elective module				
8	**Responsible** Prof. M. Aßmann, Dr. D. Reiter		**Faculty in charge** Department of Physics		

Module: Physics of the Top Quark and the Higgs Boson (**PHY7232**)				
Degree Program: Physics (M.Sc.)				
Frequency: As needed in SS	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element/Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	2
	2	Exercise	T	3	2
2	**Language:** English				
3	**Content** After an introduction to the basic properties of the top quark and the Higgs boson, the module deals with selected topics in top and Higgs physics. • **Top quark physics:** pair and single production, decay properties, measurements of top quark parameters, associated production with other particles, charge asymmetry, spin correlations, differential measurements, top quark in extensions of the Standard Model. • **Higgs boson physics:** Higgs discovery, measurements in the diphoton and ZZ* channels, measurements of Higgs boson parameters, fermionic decays, measurement of top quark-Yukawa coupling, Dihiggs production, Higgs boson in extensions of the Standard Model.				
4	**Learning outcome** Students will gain further insight into aspects of top quark and Higgs boson physics.				
5	**Examination** Course achievement: active participation in the exercise. Module examination: Graded written or oral examination depending on the number of participants.				
6	**Participation Requirements**				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics		**Faculty in charge** Department of Physics		

Module: Practical Aspects of Instrumentation (**PHY7233**)				
Degree program: Physics (M.Sc.)				
Frequency By the semester	**Duration** 1 semester	**Semester** 1st/2nd sem.	**Credits** 3/6/9	**Work load** 90/180/270 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	2
	2	Optional: exercise session	T	3	2
	3	Optional: seminar	S	3	2
2	**Language:** English				
3	**Content** 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. The exercise session offers the possibility to discuss concrete details and, if applicable, test the material of the lecture in a laboratory environment. 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	**Examination** Module examination (lecture) or module component examinations (lecture and optional exercise session and/or seminar) Course work: Active participation in the lecture and the seminar. Examination: Graded oral examination and, if applicable, graded presentation of about 30 minutes in the seminar; the exercise session is not graded.				
6	**Participation Requirements**				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics		**Faculty in charge** Department of Physics		

Module: Laboratory of Condensed Matter Physics: Time-Resolved Photoemission (**PHY7234**)				
Degree program: Physics (M.Sc.)				
Frequency As needed	**Duration** 1 semester	**Semester** 1st/2nd sem.	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	2
	2	Exercise	T	3	2
2	**Language:** English				

3 Content

The lecture will be divided into three main chapters:

1. Introduction to the ultra-high vacuum (UHV) and to the basic instrumentation employed in surface preparation/characterization. Different surface techniques will be presented and analyzed in detail from the theoretical point of view. In particular, this part will focus on:
    a. UHV environment (pumps, pressure sensor, bake-out, vacuum components)
    b. Surface preparation tools (e-beam evaporators, ion sputtering, residual gas analyzer)
    c. Surface characterization tools
        - Low energy electron diffraction
        - Auger electron spectroscopy
2. Introduction to photoemission spectroscopy
    a. Theoretical description of the process.
    b. X-ray photoemission spectroscopy (XPS) and angle-resolved photoemission spectroscopy (ARPES)
    c. Performing photoemission spectroscopy using a photoemission electron microscope.
        - Basic principles of cathode lens microscopy
        - Going from real space to momentum operation modes
3. Introduction to pump-probe photoemission spectroscopy
    a. Principle and applications of 2 photon photoemission (2PPE)
    b. Principle and applications of high harmonic generation (HHG)
    c. How to couple pump-probe measurements to photoemission electron microscopy.

The exercise session will offer instead the possibility to apply what has been discussed during the frontal lecture. In particular, this part will provide a "hand-on" approach where students will have the chance to see the different state-of-the-art techniques at work and, most importantly, use them to perform real experiments in a laboratory environment. Part of the exercise session will be dedicated to introduce the basic principles of data analysis commonly used in time-resolved photoemission spectroscopy.

4 Learning outcome

The students will acquire a basic knowledge of state-of-the-art instrumentation related to surface preparation/characterization. They will deep their knowledge from both the theoretical and practical point of view thanks to the exercise sessions. At the end of the lecture they are expected to have an overview of time-resolved photoemission spectroscopy and also a basic knowledge on the basic principles of data-analysis.

5 Examination

Two module component examinations (lecture and exercise session)

	Course work: Active participation in the lecture and the exercise session. Examination: Graded oral examination (lecture) and graded written final report (exercise session).	
6	**Participation Requirements**	
7	**Module type** Elective module	
8	**Responsible** Dr. G. Zamborlini	**Faculty of charge** Department of Physics

Module: Advanced Solid State Physics II: Magnetism and Superconductivity (**PHY7235**)				
Degree program: Physics (M.Sc.)				
Frequency in WS	**Duration** 1 Semester	**Semester** 1st /3rd sem.	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	6	4
2	**Language:** English				
3	**Content** The lecture covers the most important aspects on collective phenomena in modern condensed matter physics, particularly on magnetism and superconductivity, based on the basic knowledge of solid state physics and quantum mechanism. Besides the fundamental properties of magnetically ordered materials and superconductors, the lectures will also cover selected topics of the contemporary research. **Magnetism:** magnetic moments, magnetization, dia- and para-magnetism of localized ions and of conduction electrons, exchange interaction, spin-orbit coupling, Zeeman interaction, ferromagnetism, antiferromagnetism, magnetic anisotropy, magnetization dynamics, magnetic excitations, quantum spin dynamics, applications. **Superconductivity:** vanishing of electrical resistance, Meissner effect, flux quantization, Type-I superconductors, Type-II superconductors, Ginzburg-Landau theory, Bardeen-Cooper-Schrieffer theory, electromagnetic response, superconducting materials, applications. Literature: Kittel, C. Introduction to Solid State Physics (Wiley) Ashcroft, Neil W.; Mermin, N. David. Solid State Physics (Brooks/Cole) Gross, R.; Marx, A. Festkörperphysik (3., akt. Aufl.). (De Gruyter.) Reinhold Kleiner and Werner Buckel, Superconductivity: An Introduction (Wiley-VCH) Michael Tinkham, Introduction to Superconductivity (Dover) James. F. Annett, Superconductivity, Superfluids and Condensates (Oxford) Terry R Orlando, Kevin A. Delin, Foundations of Applied Superconductivity (Addison-Wesley)				
4	**Learning outcome** The lecture provides a comprehensive view of collective phenomena in condensed matter physics, particularly on magnetism and superconductivity. The aim is to develop an understanding in the fundamental physics and in the working principles behind the applications, for example in the fields of spin-electronics, superconducting devices, or more generally of information and communication technology.				
5	**Examination** Module exam: oral exam (30 min)				
6	**Participation Requirements**				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics			**Faculty of charge** Department of Physics	

Module: Quantum simulation with cold atoms and molecules (**PHY7238**)				
Degree Program: Physics (M.Sc.)				
Frequency: Winter term	**Duration:** 1 semester	**Semester:** 1st sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	S	3	2
2	**Language:** English				
3	**Content** Modern topics of quantum simulation with cold atoms and molecules, such as degenerate quantum gases, laser cooling, Feshbach resonances, degenerate molecules, optical lattices, quantum gas microscopes, Hubbard models, and artificial gauge fields.				
4	**Learning outcome** Students learn modern topics in experiments with ultracold atoms and molecules. In the seminar talks, students learn to present complex scientific issues and methodologies in an understandable way. Through discussions, they learn basic principles of scientific exchange and discourse.				
5	**Examination** Module examination: Graded own presentation (30 min + 15 min discussion)				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Prof. E. Narevicius Prof. C. Weitenberg	**Faculty in charge** Department of Physics			

Module: Particle physics meets astroparticle physics (**PHY7239**)				
Degree Program: Physics (M.Sc.)				
Frequency: As needed	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	S	3	2
2	**Language:** English				
3	**Content** The seminar addresses the question how particle and astroparticle physics try to give answers to fundamental open questions in modern research. Topics that could be the subject of the seminars range from the study of current problems in observational astroparticle physics (e.g. the 'muon puzzle'), to the interplay between flavour physics and astroparticle physics in understanding the universe, or related fields such as cosmology and nuclear physics.				
4	**Learning outcome** Students deepen their knowledge in the field of particle physics and astroparticle physics through self-study for their individual presentations. They understand the underlying experimental tech-niques and analyse how the topics address fundamental open questions in physics. The prepara-tion of the talks also trains skills in scientific literature research and presentation techniques. In the subsequent discussion, scientific discussion techniques are acquired to evaluate the pre-sented topics.				
5	**Examination** Course credits: Active participation in the discussion following the lectures Module examination: Graded own presentation				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Prof. J. Albrecht		**Faculty in charge** Department of Physics		

Module: Introduction to Theoretical Elementary Particle Physics (**PHY731**)				
Degree program: Physics (M.Sc.)				
Frequency: annually in WS	**Duration:** 1 semester	**Semester:** 1st sem.	**Credits** 12	**Work load** 360 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	8	4
	2	Exercise	T	4	2
2	**Language:** English				
3	**Content** Kinematics of relativistic particle reactions: Cross sections and branching ratios; Calculation of elementary processes; The Standard Model and its phenomenology: quarks, leptons, QCD and electroweak interaction, Higgs, C,P,CP,- flavor symmetries and symmetry breaking. Literature: Peskin, Schroeder: An Introduction to Quantum Field Theory; Nachtmann: Elementary Particle Physics; Georgi: Weak Interactions and modern particle physics.				
4	**Learning outcome** In the lecture, knowledge is imparted which enables participation in advanced special seminars and the preparation of a master's thesis in elementary particle physics. This includes an introduction to concepts and methods of high energy physics. In the exercises, students learn to describe simple physical systems both formally-mathematically and verbally and to present solutions by solving problems independently and discussing them in the group. In doing so, they learn to review their learning and measure it against that of their fellow students. To encourage teamwork, homework is accepted as group work by up to 3 students.				
5	**Examination** Course Credits: Homework Module examination: Graded written exam (120 min)				
6	**Participation requirements** Recommended: Advanced Quantum Mechanics				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics			**Faculty in charge** Department of Physics	

Module: Introduction to Theoretical Solid State Physics (**PHY732**)				
Degree program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st sem.	**Credits** 12	**Work load** 360h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	8	4
	2	Exercise	T	4	2
2	**Language:** English				
3	**Content** Symmetries of crystal lattices; lattice vibrations, Born-Oppenheimer approximation, approaches to crystal potential, thermodynamics of phonons, phonon spectroscopy, photon-phonon and phonon-phonon interactions; electrons in solids, band structure for nearly free and strongly bound electrons, density functional theory, modern band structure methods, dynamics of band electrons in electromagnetic fields; Electronic excitations, interactions, excitons, plasmons, shielding, overall introduction of the quasiparticle concept; fundamentals of magnetism, superconductivity phenomenological and Bardeen-Cooper-Schrieffer theory; transport in solids. Literature: e.g. Czycholl, Theoretische Festkörperphysik, Vieweg (2000).				
4	**Learning outcome** Students will learn to understand phenomena in solids as applications of quantum mechanics. Importantly, they will recognize that and how novel collective behavior emerges from the complexity of very many degrees of freedom. They are introduced to the challenging abstract description of such collective phenomena. They will learn to apply the well-known fundamental methods of solid-state theory independently. They will be enabled to work independently through monographs and review articles from the field of condensed matter physics, thereby being able to prepare seminar presentations from this field as well as to conduct a master's thesis in the fields of experimental or theoretical condensed matter physics on this basis. In the exercises, the students will learn to work out results in teamwork. Furthermore, they will learn how to communicate abstract issues appropriately to other students and to discuss their theoretical description, if necessary controversially, in a results-oriented manner.				
5	**Examination** Course Credits: Homework Module examination: Graded written or oral examination				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics		**Faculty in charge** Department of Physics		

Module: Quantum Field Theory (PHY733)				
Degree program: Physics (M.Sc.)				
Frequency: annual	**Duration:** 1 semester	**Semester:** from 1st sem.	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture with exercise	L + T	6	2+2

2	**Language:** English
3	**Content** canonical quantization Φ^4 theory, Noether theorem, correlation functions, path integral for spin 0, spin 1/2, and spin 1 fields, elements of renormalization (dimensional), and renormalization group. Literature: Mark Srednicki: Quantum Field Theory, Peskin, Schroeder: An Introduction to Quantum Field Theory
4	**Learning outcome** Students learn the most important elements of quantum field theory, as well as the methods for the technical handling of perturbation theory problems. The relativistic path integral is covered in detail as the basis for quantizing all known fields in the standard model of elementary particle physics. Elements of renormalization with one-loop calculations are part of the course. Students are introduced to methods as they are used in current research. In the exercises, students learn to describe simple physical systems both formally-mathematically and verbally and to present solutions by solving problems independently and discussing them in the group. In doing so, they learn to review their learning and measure it against that of their fellow students. To encourage teamwork, homework is accepted as group work by up to 3 students.
5	**Examination** Course Credits: Homework Module examination: Graded written examination (120 min) or oral examination (30 min) depending on the number of participants.
6	**Participation requirements** recommended: Advanced Quantum Mechanics; Introduction to Elementary Particle Theory
7	**Module type** Elective module; recommended if master's thesis in the field of particle theory is intended.

8	**Responsible** Dean of the Department of Physics	**Faculty in charge** Department of Physics

Module: Theory of Strongly Correlated Systems and Quantum Information (**PHY734**)				
Degree Program: Physics (M.Sc.)				
Frequency: every semester	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Self-study and own presentation	S	3	2
2	**Language:** English				
3	**Content** The seminar consists of subfields of current theoretical research on strongly correlated solid-state systems: Current problems in the theory of strongly correlated solid-state systems and quantum information; focus on concepts and methods, with equal emphasis on analytical and numerical aspects; development of methods and their critical evaluation; definition of theoretical issues Literature: will be announced in the seminar on the respective topics and provided if necessary.				
4	**Learning outcome** Students are introduced to current research in solid state theory. They become familiar with methods and concepts as well as their application to still unsolved problems. They become proficient in scientific discourse through the joint discussions and learn to tackle tasks in a team. By preparing and giving their own presentation, they acquire skills in scientific methodology, especially in research and presentation techniques. A special goal is to train the view for the essentials of a physical problem.				
5	**Examination** Course Credits: Active participation in the discussions following the lectures. Module examination: Graded own presentation (45-60 min) on a topic from current research.				
6	**Participation requirements** Recommended: introduction to theoretical solid state physics				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics	**Faculty in charge** Department of Physics			

Module: Introduction to the Renormalization Group (**PHY735**)				
Degree Program: Physics (M.Sc.)				
Frequency: as needed in WS	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 4	**Work load** 120 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	4	2
2	**Language:** English				
3	**Content** 1. **Fundamentals of phase transitions:** spontaneous symmetry breaking, order parameters, correlation length, critical behavior, molecular field theory, Landau theory of phase transitions. 2. **Renormalization group:** path integral of the state sum, the three steps of renormalization, Gaussian fixed point, Wilson-Fisher ε-expansion, critical exponents. 3. **Quantum critical phenomena:** generalized Landau-Ginsburg-Wilson functional, Hertzian theory, thermal and quantum fluctuations, outlook on numerical renormalization group.				
4	**Learning outcome** Students will gain insight into the basics of the Wilson renormalization group, the concept of the fixed point, and the relationship between the perturbative expansion of the RG transform around the fixed point and the calculation of critical exponents.				
5	**Examination** Module examination: Graded oral examination (30 min)				
6	**Participation Requirements** Recommended: introduction to theoretical solid state physics				
7	**Module type** Elective module				
8	**Responsible** Prof. F. Anders	**Faculty in charge** Department of Physics			

Module: Physics Beyond the Standard Model (BSM Seminar) (**PHY736**)				
Degree Program: Physics (M.Sc.)				
Frequency: every semester	**Duration:** 1 semester	**Semester:** 1st/2nd sem	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	S	3	2
2	**Language:** English				
3	**Content** Current problems in particle theory on physics beyond the Standard Model: flavor problem and observables, rare decays, effective thoeries, dark matter, Higgs sectors, quantum gravity and asymptotic security, model building and phenomenology, recent results.				
4	**Learning outcome** Students deepen their knowledge in the field of the seminar through self-study on their own lecture. This lecture also trains skills in scientific literature research and presentation techniques. In the subsequent discussion, scientific discussion techniques are acquired.				
5	**Examination** Course Credits: Active participation in the discussions following the lectures. Module examination: Graded own presentation on a current research topic.				
6	**Participation Requirements** Introduction to elementary particle physics				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics		**Faculty in charge** Department of Physics		

Module: Theoretical Problems of Condensed Matter (**PHY737**)				
Degree Program: Physics (M.Sc.)				
Frequency: every semester	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Self-study and own presentation	S	3	2
2	**Language:** English				
3	**Content** The seminar consists of subfields of current theoretical research in condensed matter theory: Current problems in the theory of solid state systems, biological and soft matter, and quantum information; focus on concepts and methods, with equal emphasis on analytical and numerical aspects; development of methods for describing equilibrium and non-equilibrium states and their critical evaluation; definition of theoretical issues Literature: will be announced in the seminar for the respective topics and provided if necessary.				
4	**Learning outcome** Students are introduced to current research in condensed matter theory. They become familiar with methods and concepts as well as their application to still unsolved problems. They become proficient in scientific discourse through the joint discussions and learn to tackle tasks in a team. By preparing and giving their own presentation, they acquire skills in scientific methodology, especially in literature research and presentation techniques. A special goal is to train the view for the essentials of a physical problem.				
5	**Examination** Course Credits: Active participation in the discussions following the lectures. Module examination: Graded own presentation (45-60 min) on a topic from current research.				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics		**Faculty in charge** Department of Physics		

Module: Hadrons in Quantum Chromodynamics (**PHY738**)				
Degree Program: Physics (M.Sc.)				
Frequency: as needed in WS	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 4	**Work load** 120 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	4	2
	This is an event offered jointly by the University of Siegen and the TU Dortmund University. Part of the lectures will be transmitted from or to Siegen via video conference.				
2	**Language:** English				
3	**Content** • Introduction to quantum chromodynamics • Quark structure and spectroscopy of hadrons • Flavour symmetries: Isospin, SU(3), chiral and heavy-quark symmetries. • Quark currents and hadronic matrix elements: Decay constants and • Form factors, phenomenology of strong interaction, • S-matrix, scattering amplitude, Mandelstam variables, • Analyticity ä t and unitarity condition, • Dispersion relations, • Introduction to Heavy-Quark Effective Theory, • QCD Vacuum and Hadrons, Quark and Gluon Condensates • Operator product development, QCD sum rules				
4	**Learning outcome** Students will gain advanced insights into theoretical and phenomenological aspects of particle physics with an emphasis on the physics of hadrons.				
5	**Examination** Module examination: Graded written examination or oral examination depending on the number of participants.				
6	**Participation Requirements**				
7	**Module type** Elective module				
8	**Responsible** Prof. A. Khodjamirian (Siegen) Prof. G. Hiller (Dortmund)			**Faculty in charge** Department of Physics	

Module: Differential Geometry / General Relativity (PHY739)				
Degree Program: Physics (M.Sc.)				
Frequency: irregular	**Duration:** 1 semester	**Semester:** 1st-3rd sem.	**Credits** 5	**Work load** 150 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	S	5	2
2	**Language:** English				
3	**Content** The mathematical structure of special solutions of the Einstein equations: The Schwarschild space-time, the Reissner Nordström and the Kerr solution, the Gödel universe. Completeness of geodesics, structure of singularities, maximal extensions, symmetries, Killing vectors, causality.				
4	**Learning outcome** The following key competencies are acquired: the ability to deal in depth and independently with an advanced mathematical or physical subject area as well as its appealing written and oral presentation in a free lecture in front of a larger audience. A further learning objective is the practice of joint scientific discourse resulting from questions and discussions. Skills acquired for the preparation of the written paper will later benefit the students in the preparation of the master's thesis.				
5	**Examination** Graded module examination. Regular attendance at the seminar sessions is a prerequisite. The practice of scientific discourse in the group as an important learning objective requires such compulsory attendance. Without this, the learning objective cannot be achieved or can only be achieved with considerable additional work load. Module examination: 90-minute oral presentation on an agreed topic and written elaboration of this presentation.				
6	**Participation requirements** Knowledge of general relativity and differential geometry				
7	**Module type** Elective module				
8	**Responsible** PD U. Löw/ Prof. L. Schwachhöfer	**Faculty in charge** Department of Physics/ Department of Mathematics			

Module: Big Questions (**PHY7310**)				
Degree Program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Self-study and own presentation	S	3	2

2	**Language:** English
3	**Content** Fundamental philosophical questions from the point of view of physics, such as "What is time?", "What is consciousness?", "How does classical reality arise from an underlying quantum description?", "What is fundamental?", "What is the relationship between matter and information?".
4	**Learning outcome** Students learn how concepts from quantum mechanics and information theory can be used to discuss fundamental philosophical questions. This can focus on different problems such as the nature of time, the understanding of consciousness, the relationship of matter and information, the question of naturalness of physical theories, the reality of parallel universes, or the relationship of quantum information processing and gravity. In addition, students also acquire presentation techniques for conveying knowledge and discussion techniques.
5	**Examination** Course Credits: Active participation in the discussions following the lectures. Module examination: Graded own presentation.
6	**Participation requirements**
7	**Module type** Elective module

8	**Responsible** Prof. H. Päs	**Faculty in charge** Department of Physics

Module: Neutrinos and Cosmology (**PHY7311**)				
Degree Program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Self-study and own presentation	S	3	2

2	**Language:** English
3	**Content** Current research in cosmology and neutrino physics.
4	**Learning outcome** Students learn to work through current research papers in the fields of cosmology and neutrino physics, as well as to deal with English-language literature in general. In addition, students also acquire presentation techniques for conveying knowledge and discussion techniques.
5	**Examination** Course Credits: Active participation in the discussions following the lectures. Module examination: Graded own presentation.
6	**Participation Requirements** Recommended: Advanced quantum mechanics, introduction to elementary particle theory, cosmology.
7	**Module type** Elective module

8	**Responsible** Prof. H. Päs	**Faculty in charge** Department of Physics

Module: Theory of Magnetism in Solids (**PHY7312**)				
Degree Program: Physics (M.Sc.)				
Frequency: irregular	**Duration:** 1 semester	**Semester:** 1st-3rd sem.	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L + T	6	2+1
2	**Language:** English				
3	**Content** Models for describing magnetic order in solids; theorems for magnetic order in solids; ground state properties and thermodynamics of magnetically ordered solids; excitations and response functions in magnetically ordered solids; many-body methods for studying magnetic order in solids. Literature: W. Nolting and A. Ramakanth, "Quantum Theory of Magnetism," (Springer, 2009); P. Fazekas, "Lecture Notes on Electron Correlation and Magnetism" (World Scientific, 1999); N. Majilis, "The Quantum Theory of Magnetism" (World Scientific, 2007).				
4	**Learning outcome** The students learn the use of canonical many-body methods on the special problem of magnetic order in solids. In addition, they learn under which conditions magnetic order can occur in solids and which properties the systems ordered in this way have.				
5	**Examination** Module examination: Graded oral examination (30 min)				
6	**Participation requirements** Recommended: introduction to theoretical solid state physics				
7	**Module type** Elective module				
8	**Responsible** PD J. Bünemann		**Faculty in charge** Department of Physics		

Module: Theory of Soft and Biological Matter (**PHY7313**)				
Degree Program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st sem.	**Credits** 5	**Work load** 150 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture with exercise	L+T	5	2 + 1
2	**Language:** English				
3	**Content** Important soft and biological matter systems: colloidal systems, liquid crystals, polymers, fluid interfaces, fluid membranes; Cell membrane, DNA, cytoskeleton, proteins, motor proteins, protein filaments. • **Statistical physics:** virial expansion, phase transitions (MeanField, scale laws). • **Molecular interactions:** Debye-Hückel theory, van der Waals interaction, DLVO theory, hydrophobic effect, hydrogen bonds, steric interactions. • **Polymers:** chain models, self-avoidance, polymer solutions, adsorption, rubber elasticity. • **Fluid interfaces:** surface tension, differential geometry, surfaces of constant curvature, capillary waves, wetting, foams. • **Membranes:** bending energy, shapes of liquid vesicles, thermal fluctuations.				
4	**Learning outcome** Students will be able to apply the modern methods of theoretical physics (from the areas of statistical physics, mechanics, electrodynamics) to systems of soft matter and biological physics in an interdisciplinary manner. In the exercises, students learn to independently grasp problems from the interdisciplinary subject area of soft matter as a theoretical-physical problem, to solve them and to discuss them in the group.				
5	**Examination** Course work: Exercises. Module examination: Graded written exam (120min) or oral exam (30 min), will be announced at the beginning of the course.				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Prof. J. Kierfeld		**Faculty in charge** Department of Physics		

Module: Quantum Theory of Semiconductors (**PHY7314**)				
Degree program: Physics (M.Sc.)				
Frequency As needed	**Duration** 1 semester	**Semester** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	2
2	**Language:** English				
3	**Content** Semiconductors play a vital role in modern devices used in computers, smartphones and quantum technologies. Using a microscopic description of semiconductors, the lecture will introduce the basic concepts of semiconductor theory. The lecture covers several topics from semiconductor physics including semiconductor band structures, heterostructures, excitons, light-matter interaction, transport theory as well as two dimensional materials like graphene or transition metal dichalcogenides. This gives a solid background to understand modern research papers. Literature: A script will be provided during the lecture.				
4	**Learning outcome** The students acquire fundamental knowledge of semiconductor physics, such that they are able to understand and explain different phenomena observed in semiconductors. Additionally, they learn how to theoretically model semiconductors and their nanostructures.				
5	**Examination** Graded oral examination (20-30min)				
6	**Participation requirements** Recommended: introduction to theoretical solid state physics				
7	**Module type** Elective module				
8	**Responsible** Dr. D. Reiter			**Faculty of charge** Department of Physics	

Module: Ask me anything: Quantum Dots (**PHY7315**)				
Degree program: Physics (M.Sc.)				
Frequency As needed	**Duration** 1 semester	**Semester** 1st/2nd Sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar/Directed discussion	S	3	2
2	**Language:** English				
3	**Content** This topic of this seminar is the physics and theoretical description of semiconductor quantum dots. Quantum dots are prime examples for few-level systems and can be excited by optical fields, while still being solid-state objects. As photon sources, they are actively used in state-of-the-art devices in quantum technologies. Therefore, discussing quantum dots covers aspects from solid-state theory, semiconductor physics and quantum optics. Examples for topics are state preparation schemes for quantum dots like Rabi rotations or adiabatic rapid passage, electron-phonon interaction and the reappearance regime, magnetically doped quantum dots, photonic states generated by quantum dots in a cavity, entangled photon generation from quantum dots. To cover these topics, the students are given material (either lecture notes, fundamental papers or recent research articles) covering one session. Each session will be hosted by a student, who is responsible for asking questions to the lecturer, such that the full content of the session is covered. The chair shall also involve other students to participate in the discussions.				
4	**Learning outcome** The students acquire in-depth knowledge about a modern topic of physics. This includes self-study of an advanced topics in solid-state theory. By taking the active role of the chair, the students to learn how to ask questions and moderate a discussion. The seminar language shall be English, such that the students learn how to formulate questions and discuss in the language spoken at most conferences.				
5	**Examination** Course work: Active participation in the seminar Graded chairing of one seminar session				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Dr. D. Reiter		**Faculty of charge** Department of Physics		

Module: Advanced Topics in Quantum Field Theory (**PHY7316**)				
Degree program: Physics (M.Sc.)				
Frequency As needed	**Duration** 1 semester	**Semester** From 1st sem.	**Credits** 6	**Work load** 240 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	2
	2	exercise session / seminar session	T/S	3	2
2	**Language:** English				
3	**Content** This course covers advanced topics of quantum field theory that typically have not been covered in depth in the mandatory course of "Theoretical Elementary Particle Physics". Key topics: • Quantisation of non-abelian gauge theories • Renormalization in QED and QCD • Effective field theories • Renormalisation with EFTs • Spontaneous symmetry breaking of global symmetries				
4	**Learning outcome** The students acquire basic knowledge of the concepts and computational methods required for research projects in theoretical particle physics. The concepts of renormalisation and effective field theories are introduced and illustrated in terms of examples relevant to modern particle physics. Self-reading and the use of available computer algebra tools is encouraged and promoted through the exercise/seminar session.				
5	**Examination** Course work: active participation in the lecture and the exercise sessions. Module examination (lecture) or module component examinations (lecture and optional exercise session and/or seminar)				
6	**Participation requirements** Recommended: introduction to theoretical particle physics, quantum field theory				
7	**Module type** Elective module				
8	**Responsible** Prof. E. Stamou		**Faculty of charge** Department of Physics		

Module: From Standard Model to BSM Physics (**PHY7317**)				
Degree Program: Physics (M.Sc.)				
Frequency: in SS	**Duration:** 1 semester	**Semester:** 2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours**
	1	Lecture	L	3	2
2	**Language:** English				
3	**Content** Concepts of modern particle physics models; The ingredients of the Standard model and directions and phenomenological tool to BSM model building. • **Standard Model:** Lagrangian, Matter, Symmetries • **BSM:** flavor, leptoquarks, vector-like fermions, Z' models, model-independent approaches, stability, landau poles • **Tools:** Computing tools for practicioners: FIts, Cross sections, Wilson coefficients, beta-functions and evolution				
4	**Learning outcome** Students understand the foundations of SM and modern concepts to BSM physics. Indepth analysis of BSM benchmarks and intriduction of tools allows them to pursue research in particle theory and phenomenology.				
5	**Examination** academic performance: active participation Module examination: Lecture (30 min) or written exam				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Prof. G. Hiller		**Faculty in charge** Department of Physics		

Module: Advanced Laboratory Course for Master Students I (**PHY742**)				
Degree program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st semester	**Credits** 6	**Work load** 180h

1	**Module structure** 4 contact hours per week, laboratory course; experiments are performed in small groups, and supervised by experienced scientists.	
2	**Language:** English	
3	**Content** Physical experiments and measurement methods: The knowledge and skills acquired by the students from the laboratory courses of the Bachelor's program are deepened and extended with regard to current techniques. Advanced experiments on elementary particle, nuclear, atomic and solid state physics are carried out The respective experimental instructions contain only a brief outline of the theoretical and experimental basics, so that the required knowledge must be acquired through self-study and the handling of (English) journals is learned. Literature: A script will be provided. Additional literature required for understanding e.g.: Bergmann, Schäfer, Textbook of Experimental Physics 1-6 (Walter de Gruyter 1990) Leo, Techniques for Nuclear and Particle Physics Experiments (Springer 1994). Thorne, Litzen, Johansson, Spectrophysics (Springer 1999). Trade journal articles	
4	**Learning outcome** The students are able to independently understand, perform and analyze complex experiments and to present the facts scientifically. They have learned to familiarize themselves independently with a topic (with English-language literature), as well as to select and apply a suitable method from various measurement techniques or analysis methods. Students have learned to look for errors and to correct them if necessary. The students are able to formulate a scientific work process linguistically, to document it and to discuss its results critically. They have learned to work in a team and to communicate scientifically with each other.	
5	**Examination** Course credits: Preparation, experimental performance and tested experimental protocols. Module examination: Graded oral examination (30 min).	
6	**Participation requirements**	
7	**Module type** Mandatory module	
8	**Responsible** Dean of the Department of Physics	**Faculty in charge** Department of Physics

Module: Applied Proton Therapy (**KM09/APM11**)				
Degree Program: Physics (M.Sc.)				
Frequency: in SS	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Computer Lab	P	6	4
2	**Language:** English				
3	**Content** Basics of the Monte Carlo simulation method • Interaction of ionizing radiation and description by means of computer simulations • Focus: Proton radiation and field shaping for clinical applications in radiation therapy • Simulation of patient irradiation by integration of CT image data sets • other changing topics: e.g. radiation protection or biological effectiveness In each course, a compact introduction to the topic is followed by its direct implementation in simulations to be created by the students themselves. In a final project work, a complete irradiation is simulated and evaluated from a clinical point of view.				
4	**Learning outcome** After successful completion of the module, students can • Name the basics of Monte Carlo (MC) simulation techniques and apply them to specific problems involving ionizing radiation. • Interpret and process results from simulations and present them in an appropriate manner. • Explain the effect of individual components of different beam shaping techniques for clinical treatment fields and recreate them using computer simulations. • Recognize and explain differences in the physical dose distribution of various types of radiation and irradiation techniques. • Explain the data structure of the clinical standard file format (DICOM) and display, read and process content in suitable software. • Describe the creation of simple proton irradiation plans, evaluate them from a clinical perspective, and apply what they have learned to a specific project.				
5	**Examination** Course achievement: written project report Module exam: will be announced at the beginning of the course.				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** JProf. A. Lühr		**Faculty in charge** Department of Physics		

Module: Flavor Physics in Experiment and Theory (**PHY811**)				
Degree Program: Physics (M.Sc.)				
Frequency: as needed in SS	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	4.5	3
	2	Exercise	T	1.5	1
	This is an event offered jointly by the University of Siegen and the TU Dortmund University. Part of the lectures will be transmitted from or to Siegen via video conference.				
2	**Language:** English				
3	**Content** Historical introduction to flavor physics from theoretical and experimental points of view. Flavour structure of the Standard Model, derivation of the quark mixing matrix (CKM), measurement of the CKM parameters, detailed discussion of CP violation, measurement of CP-violating parameters, short-range structure of flavour transitions, effective Hamiltonian of flavour-changing processes, theory of exclusive decays, measurements on electroweak penguin decays, lepton flavour physics, top flavour physics.				
4	**Learning outcome** Students will gain advanced insights into theoretical and experimental aspects of flavor physics. About half of the lecture is given as a theory lecture and half as an experimental physics lecture.				
5	**Examination** Course credits: active participation in the exercise. Module examination: Graded written or oral examination depending on the number of participants.				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Prof. Th. Mannel (Siegen) Prof. J. Albrecht (Dortmund)		**Faculty in charge** Department of Physics		

Module: Accelerator Physics II (**PHY812**)				
Degree Program: Physics (M.Sc.)				
Frequency: in SS	**Duration:** 1 semester	**Semester:** 2nd sem.	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	2
	2	Exercise / Seminar	T/S	3	2
2	**Language:** English				
3	**Content** **Brief review of the basics:** Longitudinal and transverse beam dynamics, synchrotron radiation **A selection coordinated with students from the following special topics:** Superconducting magnets and high-frequency structures, beam diagnostics, ultrashort radiation pulse generation, free-electron laser theory, collective phenomena in storage rings, beam cooling, Hamiltonian beam dynamics, special accelerator facilities (e.g., energy-recovery linear accelerators, spallation sources, neutrino factories), new concepts (e.g., laser-plasma accelerators). **Field trip to an out-of-town accelerator laboratory**				
4	**Learning outcome** Students learn about several current research topics in the field of accelerator physics, aiming for a balanced mix of theory, experimental physics and accelerator technology. Students will perform calculations on the respective topics in exercises, including practicing the use of a scripting language such as Matlab. The seminar program consists of one lecture per participant, possibly supplemented by guest lectures. In this way, the students practice working independently on a special topic and presenting it in a comprehensible way.				
5	**Examination** Module examination: Graded oral examination (30 min). The following course work must be completed as a prerequisite for admission: Regular successful completion of the exercise tasks, active participation in the exercises, a Seminar presentation (20-30 min)				
6	**Participation Requirements:** Participation in the module Accelerator Physics I.				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics	**Faculty in charge** Department of Physics			

Module: Experimental aspects of particle physics (**PHY822**)				
Degree program: Physics (M.Sc.)				
Frequency in SS	**Duration** 1 semester	**Semester** 2nd sem.	**Credits** 6	**Work load** 120 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	2
	2	Exercise	T	3	2
2	**Language:** English				
3	**Content** Experimental aspects of particle physics with varying focus, e.g. searches for new phenomena, precision measurements, current and future experiments. Basic experimental methods in accelerator-based particle physics.				
4	**Learning outcome** This subject focus on experimental techniques necessary to perform measurements in the field of particle physics. Students will learn in-depth aspects in the subject area, with particular attention to data analysis. They will acquire the necessary knowledge and skill to treat complex measurements and systematics effects. In addition to professional training, at the end of the course, students will be able to read critically original literature.				
5	**Examination** Coursework: Active participation in the exercise sessions. Graded module examination (oral or written)				
6	**Participation Requirements**				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics		**Faculty in charge** Department of Physics		

Module: Astroparticle Physics (**PHY823**)				
Degree Program: Physics (M.Sc.)				
Frequency: in SS	**Duration:** 1 semester	**Semester:** 2nd sem.	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture with integrated exercise	L+T	6	4
2	**Language:** English				

3 Content

1. **Cosmic rays:**
   nuclei, electrons, photons, neutrinos, detection of energetic particles, acceleration mechanisms, propagation of particles through the interstellar medium, interaction and decay, galactic magnetic fields, cosmic background radiation, infrared background, cosmological aspects, star and galaxy formation.
2. **Astrophysical sources:**
   Remnants of stellar explosions, compact objects (black holes, neutron stars), shock waves in the ejected stellar envelope, molecular clouds, starburst - galaxies, galaxy clusters, supernovae, binary systems, microquasars, nuclei of active galaxies, gamma ray bursts.
3. **Particle Physics Sources:**
   Spallation, Dark Matter (WIMPs), Topological Defects, Monopoles, Proton Decay, Axions,
4. **Particle Physics Measurements:**
   including effective cross sections, energy loss in the medium, neutrino oscillations, physics at highest energies.
5. **Detection instruments:**
   optical telescopes, radio telescopes, air shower facilities, gamma-ray telescopes, neutrino telescopes, satellite experiments, low energy detectors.
6. **Practical consequences:**
   biological consequences, technological consequences.

Literature:

Astroparticle Physics. The universe in the light of cosmic rays, Claus Grupen. Springer, Heidelberg 2000.
particle astrophysics. Hans Volker Klapdor-Kleingrothaus, Kai Zuber, Stuttgart 1997.
astroparticle physics: theory and phenomenology, Günter Sigl, Atlantis Press 2016.
cosmic rays and particle physics, Thomas Gaisser, Cambridge 2016.
cosmic ray astrophysics, Reinhard Schlickeiser, Berlin Heidelberg New York 2002,
An Introduction to Modern Astrophysics, Bradley W. Carroll, Dale A. Ostlie, Reading, Menlo Park New York.

4 Learning outcome

The students learn about topics from the frontier area between astronomy, nuclear and particle physics and cosmology and their interdisciplinary discussion. Students also learn argumentation techniques based on the interaction of theory and experiment. Phenomenological calculations are used to learn how to plan and test the scope of experiments.

5 Examination

Course achievements: successful participation in the exercises.
Module exam: Graded written or oral exam, will be announced at the beginning of the course

6 Participation requirements

7	**Module type** Elective module	
8	**Responsible** Prof. W. Rhode	**Faculty in charge** Department of Physics

Module: Astroparticle Physics II (**PHY823.2**)				
Degree Program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture with integrated exercise	L+T	3	2
2	**Language:** English				

3 Content

1. **Early universe:**
   big bang, inflation and thermal evolution of the cosmos. Freeze-out and heavy relics. Cosmic neutrino background.
2. **Propagation of energetic particles:**
   Absorption processes, extragalactic radiation fields, plasmas in interstellar and intergalactic space, particle interactions.
3. **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.
4. **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.
5. **Gravitational waves:**
   experimental detection methods and multi-messenger astronomy.

Literature:
Cosmic Ray Astrophysics, Reinhard Schlickeiser, Berlin Heidelberg New York 2002.
Gravitation and Cosmology: Principles And Applications Of The General Theory Of Relativity, Steven Weinberg, Wiley India, 2017.
Gravity, Black Holes, and the Very Early Universe. An Introduction to General Relativity and Cosmology, Tai L. Chow, Springer 2007.

4 Learning outcome
Students learn about topics 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 assessment of recent experimental and theoretical publications are also learned.

5 Examination
Graded module examination

6 Forms of examination and performance
Course achievement: Active participation in the exercises
Module examination: written (written exam 120 min) or oral (30 min), will be announced at the beginning.

7 Participation Requirements
Recommended: astroparticle physics

8 Module type
Elective module

9	**Responsible** Prof. W. Rhode	**Faculty in charge** Department of Physics

Module: Fundamentals of Detector Physics (**PHY825**)				
Degree Program: Physics (M.Sc.)				
Frequency: annually in SS	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	2
2	**Language:** English				
3	**Content** Interactions of charged, neutral particles and of photons with matter, overview of overall detector systems, gas-filled ionization detectors (types and modes of operation, ionization and charge loss, motion in elctr. and magn. field, proportional chambers, drift chambers) Field, proportional chambers, drift chambers, semiconductor detectors (basics, pn-junction and interfaces, types, pixel detectors), scintillation detectors (function, applications), calorimetry (electromagnetic and hadronic, homogeneous and sampling), particle identification, trigger systems, data acquisition systems (DAQ)				
4	**Learning outcome** Students gain an overview of the various detector designs used in particle physics, medical physics, and other fields. In particular, they learn the relationship between the respective primary interactions of the particles to be detected with the total matter traversed and the fractions exploited by the respective detector design. This leads to an understanding of the respective advantages and disadvantages of the construction types for different application purposes. Furthermore, the students are enabled to work with original literature.				
5	**Examination** Course credits: none. Module Exam: Graded written or oral examination.				
6	**Participation Requirements**				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics		**Faculty in charge** Department of Physics		

Module: Detector systems in particle and medical physics (**PHY826**)				
Degree program: Physics (M.Sc.)				
Frequency in WS	**Duration** 1 semester	**Semester** 1st sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	S	3	2
2	**Language:** English				
3	**Content** 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 seminar will deepen the knowledge of the different types of detectors which are used in particle physics and in medical physics. The important lectures on systems and trigger systems allow to understand the interplay of the different detector designs to be understood. The prescribed own lecture leads to a very intensive study of a special topic and also trains competences in the field of scientific literature research and presentation techniques.				
5	**Examination** Coursework: Active participation in the discussion. Graded module examination: oral presentation on one of the topics of the seminar				
6	**Participation Requirements** Recommended: Fundamentals of Detector Physics				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics		**Organization** Department of Physics		

Module: False Discoveries in Particle Physics (**PHY827**)				
Degree Program: Physics (M.Sc.)				
Frequency: As needed	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Self-study and own presentation	S	3	2
2	**Language:** English				
3	**Content** The seminar deals with discoveries in particle physics, which in retrospect turned out to be erroneous. Literature: will be announced or provided in the seminar on the respective topics.				
4	**Learning outcome** Students deepen their knowledge in the field of the seminar through self-study on your own lecture. This lecture also trains skills in the area of scientific literature research and presentation techniques. In the subsequent discussion scientific discussion techniques acquired. In addition to these classical competences, the seminar helps students to become aware of the rules of good scientific practice and to reflect on possible problems.				
5	**Examination** Course Credits: Active participation in the discussions following the lectures. Module examination: Graded own presentation.				
6	**Participation Requirements** Recommended: astroparticle physics.				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics		**Faculty in charge** Department of Physics		

Module: Structural Analysis with X-rays (**PHY829**)				
Degree Program: Physics (M.Sc.)				
Frequency: in SS	**Duration:** 2 weeks Block course	**Semester:** 1st/2nd sem.	**Credits** 5	**Work load** 150 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Block course	L	3	2
	2	Exercises and self-study	T	2	1
2	**Language:** English				
3	**Content** 1. **Structure of ideal crystals:** description of periodic structures, fundamental lattice types, lattice planes, examples of simple crystal structures. 2. **X-ray structure analysis:** diffraction of waves at the crystal, Laue interference function, reciprocal lattice, methods of X-ray structure analysis, structure factor, phase problem, non-ideal crystal structures, amorphous structures, scattering at the surface. 3. **Special X-ray techniques:** X-ray reflectometry, small angle X-ray scattering, absorption spectroscopy, fluorescence spectroscopy, X-ray Raman scattering. 4. **Modern X-ray sources:** X-ray tube, synchrotron radiation sources, X-ray laser.				
4	**Learning outcome** Students learn the basic description of crystal structures, the fundamentals of structure elucidation with X-rays and various applications of the corresponding experimental methods. They gain an overview of the different X-ray methods that can be used for the structural elucidation of crystalline and non-crystalline systems.				
5	**Examination:** Graded written or oral module examination; to be announced at the beginning of the course.				
6	**Participation Requirements**				
7	**Module type** Elective module				
8	**Responsible** Dr. C. Sternemann, Dr. M. Paulus	**Faculty in charge** Department of Physics			

Module: External School in Particle Physics (**PHY8210**)				
Degree Program: Physics (M.Sc.)				
Frequency: irregular	**Duration:** (min.) 1 week block course	**Semester:** 1st/2nd sem.	**Credits** 1	**Work load** 30 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Block course	L	1	Block course
2	**Language:** English				
3	**Content** The content depends on the topic of the external school and comes from the field of particle physics or the methods used there, e.g. data analysis and statistics, Monte Carlo generators or programming. The school must include an exercise and correspond to a course load of at least 2 Contact hours per week (30h).				
4	**Learning outcome** The students should deepen the specialist knowledge they have been taught and benefit from the experience of the external experts. In doing so, they should also network with fellow students from other universities and the lecturers.				
5	**Examination** Ungraded module (even if an in-school exam is offered graded). Course credit: none. Module examination: either internal school examination or, if this is not offered, a written summary of the school.				
6	**Participation Requirements**				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics		**Faculty in charge** Department of Physics		

Module: Applications of Synchrotron Radiation (**PHY8211a**)				
Degree Program: Physics (M.Sc.)				
Frequency: in SS	**Duration:** 1 semester	**Semester:** 1st-4th sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	2

2 Language: English

3 Content

The course will cover the following topics:

1. **Generation of synchrotron radiation**:
   operating principle of a storage ring, relativistic description of a charge moving in a magnetic field, insertion devices, X-ray optics and scheme of a beamline.
2. **X-ray interaction with matter:**
   scattering and absorption in the classical approach (Maxwell equations and dumped Lorentz oscillators) and semi-classical approach.
3. **Applications of synchrotron radiation:**
   photoemission techniques (X-ray photoemission spectroscopy and microscopy, angle-resolved photoemission spectroscopy, X-ray photoelectron diffraction, spin polarized photoemission spectroscopy) and their applications, e.g. chemical/structural analysis and study of the electronic properties of the matter with/without spatial resolution. Absorption techniques (X-ray absorption spectroscopy, X-ray magnetic circular dichroism) and their applications, e.g. study of the magnetic and chemical properties of the matter. Diffraction techniques, from crystal and powder.

4 Learning outcome

The aim of the course is to provide a basic knowledge on the main parameters involved in a synchrotron-based experiment, as well as to have an overview on the most important techniques that can be performed, with a special focus on the photoemission-related experiments.

5 Examination

Graded oral examination:

6 Participation requirements

7 Module type

Elective module

8	**Responsible** Dr. G. Zamborlini	**ResponsibleFaculty** Department of Physics

Module: Applications of Synchrotron Radiation (**PHY8211b**)				
Degree Program: Physics (M.Sc.)				
Frequency: in SS	**Duration:** 1 semester	**Semester:** 1st-4th sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	S	3	2
2	**Language:** English				
3	**Content** The course will cover the following topics: 1. **Generation of synchrotron radiation**: operating principle of a storage ring, relativistic description of a charge moving in a magnetic field, insertion devices, X-ray optics and scheme of a beamline. 2. **X-ray interaction with matter:** scattering and absorption in the classical approach (Maxwell equations and dumped Lorentz oscillators) and semi-classical approach. 3. **Applications of synchrotron radiation:** photoemission techniques (X-ray photoemission spectroscopy and microscopy, angle-resolved photoemission spectroscopy, X-ray photoelectron diffraction, spin polarized photoemission spectroscopy) and their applications, e.g. chemical/structural analysis and study of the electronic properties of the matter with/without spatial resolution. Absorption techniques (X-ray absorption spectroscopy, X-ray magnetic circular dichroism) and their applications, e.g. study of the magnetic and chemical properties of the matter. Diffraction techniques, from crystal and powder.				
4	**Learning outcome** The aim of the course is to provide a basic knowledge on the main parameters involved in a synchrotron-based experiment, as well as to have an overview on the most important techniques that can be performed, with a special focus on the photoemission-related experiments.				
5	**Examination** Graded own presentation				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Dr. G. Zamborlini		**ResponsibleFaculty** Department of Physics		

Module: Light-Matter Interaction (PHY8212)				
Degree Program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st-3rd sem.	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours**
	1	Lecture	L	4	3
	2	Exercise	T	2	1
2	**Language:** English				
3	**Content** The lecture covers the fundamentals of light-matter interaction in solids and molecules with references to current research and modern applications. After the introduction of linear optical properties of metals, semiconductors and dielectrics, concepts of nonlinear optics in perturbative and non-perturbative approximation are explained. In the exercise, these aspects are deepened by application-relevant exercises with reference to modern experiments. 1. **Linear optics:** linear optical properties of atoms, molecules, and solids; atomic line spectra; band spectra of molecules; optical properties of solids including semiconductor structures; phonons, plasmons, polarons, excitons, optical Bloch equations; density matrix formalism; strong and ultra-strong light-matter coupling. 2. **Nonlinear optics:** nonlinear susceptibility; nonlinear wave equation; phase matching; 3rd and higher order nonlinearities; nonlinear optics of the two-level system. 3. **Fundamentals of quantum optics:** quantization of the electromagnetic field; quantum-mechanical states of the light field; coherence.				
4	**Learning outcome** The lecture opens a comprehensive view on the optical properties of condensed matter in a broad spectral range from microwave radiation to the ultraviolet. The aim is to develop an understanding in particular of collective electron dynamics, excitations of quasiparticles, nonlinear optical processes and basic features of quantum optics.				
5	**Examination:** Module examination: oral				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Prof. C. Lange		**Faculty in charge** Department of Physics		

Module: Light-Matter Interaction (PHY8213)				
Degree Program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st-3rd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	S	3	2
2	**Language:** English				
3	**Content** The content of the seminar is based on the parallel lecture, which is strongly recommended. Like the lecture, the seminar focuses on the fundamentals of light-matter interaction in solids and molecules and provides references to current research and modern applications. The content includes linear optical properties of metals, semiconductors and dielectrics as well as concepts of nonlinear optics in perturbative and non-perturbative approximation. Students develop and give an independent seminar presentation on a topic of their choice with reference to the topics from the lecture. Depending on the topic, the focus is on fundamentals or applications. Possible seminar topics include: Kramers-Kronig relations, birefringence, Gaussian optics, plasmonics, light conduction in optical fibers, nonlinear fiber optics, polymer optics, lasers, femtosecond pulse generation, ultrashort pulse characterization, four-wave mixing, high harmonic generation, frequency combs, metamaterials and subwavelength resonators, entangled photons, near-field microscopy, single photon sources, EPR paradox, FTIR spectroscopy, CCD spectrometers, Raman spectroscopy, organic LEDs, quantum cascade lasers, solar cells, dispersion and compression of ultrashort laser pulses, and others.				
4	**Learning outcome** The seminar gives the participants the opportunity to deepen their knowledge of a topic in modern optics and to present it to the group.				
5	**Examination:** Module examination: Graded seminar presentation				
6	**Participation requirements** Recommended as addition to the lecture "Light-Matter Interaction"				
7	**Module type** Elective module				
8	**Responsible** Prof. C. Lange	**Faculty in charge** Department of Physics			

Module: Many-Particle Solid-State Theory (**PHY831**)				
Degree programm: Physics (M.Sc.)				
Frequency: As needed	**Duration:** 1 semester	**Semester:** 2nd sem.	**Credits** 6	**Work load** 180 h

1 Module structure

No.	Element / Course	Type	Credits	Contact hours per week
1	Lecture + exercise	L + T	6	3+1
Or: 2	Lecture	L	6	4

2 Language: English

3 Content

1. **General:**
   Deepening of the quasiparticle concept and its limits.
2. **Diagrammatic perturbation theory:**
   Green functions, derivation of Feynman diagrams, self-energy, dyson equation, vertex corrections, random phase approximation, microscopic Fermi liquid theory, dynamical molecular field theory;
3. **Renormalization:**
   e.g. poor man's scaling, functional renormalization, continuous unitary transformations;
4. **Luttinger liquid:**
   bosonization, one-dimensional systems, perturbations;
5. **Transport:**
   Kubo approach, Boltzmann equation, Landauer-Büttiker formula;
6. **Applications:**
   e.g. superconductivity, magnetism, transport, decoherence.

Literature: e.g.,
G. Rickayzen, Green's Functions and Condensed Matter, Academic Press (1988);
A.A. Abrikosov, L.P. Gorkov, and I. E. Dzyaloshinski, Methods of Quantum Field Theory in Statistical Physics, Dover (1975);
A.L. Fetter and J.D. Walecka, Quantum Theory of Many-Particle Systems, McGraw-Hill (1971);
Th. Giamarchi, Quantum Physics in One Dimension, Oxford Science Publications, (2004);
A.O. Gogolin, A.A. Nersesyan and A.M. Tsvelik, Bosonization and Strongly Correlated Systems, Cambridge University Press (1998).

4 Learning outcome

Students are introduced to the level of current research. The relevant concepts of the research field are presented, methodologically underpinned and illustrated with examples. To this end, students will become familiar with the advanced methods of condensed matter theory and critically evaluate their advantages and disadvantages themselves. They will acquire the competence to successfully complete a master's thesis in condensed matter theory.
Exercises and/or lectures will introduce students to the ways of scientific discourse.

5 Examination

Course Credits: Homework, if exercises offered.
Module examination: Graded oral module examination (30min) or written module examination.

6 Participation requirements

Recommended: Introduction to Theoretical Solid State Physics

7 Module type

Elective module

8	**Responsible** Dean of the Department of Physics	**Faculty in charge** Department of Physics

Module: Cosmology (**PHY832a**)				
Degree Program: Physics (M.Sc.)				
Frequency: As needed	**Duration:** 1 semester	**Semester:** 1st-3rd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Cosmology	L	3	2
2	**Language:** English				
3	**Content** Structures in and history of the universe, gravity and Robertson-Walker metric, world models, thermal evolution of the universe, primordial nucleosynthesis, recombination, structure formation, baryogenesis, dark matter, phase transitions in the early universe, inflation, CMB and precision cosmology. Literature: L. Bergström, A Goobar: Cosmology and Particle Astrophysics; D. Bailin, A. Love: Cosmology in gauge field theory and string theory; E.W. Kolb, M. Turner: The Early Universe; S. Weinberg: Cosmology				
4	**Learning outcome** Students are introduced to the physics of emergence and the early universe. They learn about a field of physics that is still developing, both in terms of observations and theory building; they recognize how hypotheses develop and modify in interaction with experimental observations. They see how physics on cosmic scales and physics on subnuclear scales are mutually dependent and influence each other in theory building.				
5	**Examination** Module examination: Graded oral module examination (30min) or written examination (120 min)				
6	**Participation requirements** Recommended: introduction to theoretical elementary particle physics, general relativity.				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics		**Faculty in charge** Department of Physics		

Module: Cosmology (**PHY832b**)				
Degree Program: Physics (M.Sc.)				
Frequency: As needed	**Duration:** 1 Semester	**Semester:** 1st/2nd sem.	**Credits** 6	**Woek load** 180 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture with exercise	L + T	6	2+2
2	**Language:** English				
3	**Content** Gravity and Robertson-Walker metric, Thermal evolution in the universe, Primordial nucleosynthesis, Recombination, Structure formation, Baryogenesis, Dark Matter, Dark Energy, Inflation				
4	**Learning outcome** Students gain an insight into the basics of cosmology and learn fundamental skills how important processes in the early universe are described and quantitative predictions are made to be able to describe and analyze processes such as dark matter production, baryogenesis or inflation.				
5	**Examination** Graded written exam				
6	**Participation requirements** Recommended: introduction to theoretical elementary particle physics, general relativity.				
7	**Module type** Elective module				
8	**Responsible** Prof. H. Päs		**Faculty in charge** Department of Physics		

Module: Flavor Physics (**PHY833**)				
Degree programm: Physics (M.Sc.)				
Frequency: Annual	**Duration:** 1 semester	**Semester:** 1st/ 2nd sem.	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture with exercise	L+T	6	3+2
2	**Language:** English				
3	**Content** The lecture is intended for interested students in higher semesters with previous knowledge in theoretical particle physics such as the Standard Model and the calculation of simple elementary processes. The aim of the course is to provide basic theoretical knowledge for a master thesis or more in the field of flavor physics. The lecture also focuses on phenomenology and signatures at the LHC(b) as well as superflavor factories and is therefore also addressed to ambitious experimental physicists. Topics to be covered include: Flavor and CP in the Standard Model, rare processes, flavor symmetries, minimal flavor violation, neutrinos, flavor beyond the Standard Model, in particular supersymmetry, lepton flavor, electric dipole moments. Literature: current references from lecture; Brock, Schoerner-Sadenius: Physics at the Terascale				
4	**Learning outcome** Students are introduced to methods as they are used in current research. In the exercises, students learn to describe simple physical systems both formally-mathematically and verbally and to present solutions by solving problems independently and discussing them in the group. In doing so, they learn to review their learning and measure it against that of their fellow students. To encourage teamwork, homework is accepted as group work by up to 3 students.				
5	**Examination** Course Credits: Homework. Module examination: Graded written (120 min) or oral examination depending on the number of participants.				
6	**Participation requirements**				
7	**Module type** Elective module; recommended if a Master's thesis in the area of focus flavor physics (hadronic, leptonic/neutrinos) is aimed for in the area of theory or experiment.				
8	**Responsible** Dean of the Department of Physics	**Faculty in charge** Department of Physics			

Module: Introduction to Renormalization of Quantum Field Theories (PHY834)				
Degree Program: Physics (M.Sc.)				
Frequency: As needed	**Duration:** Block course	**Semester:** 1st/2nd sem.	**Credits** 2	**Work load** 60 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	2	14 h block course
2	**Language: English**				
3	**Content** 1. **Renormalizable and Unrenormalizable QFTs:** Power Counting and examples for renormalizable and unrenormalizable theories; dimensional regularization; Ward-identities and other basic concepts of renormalization. 2. **Dyson-Ward Renormalization of QED:** The Dyson-Ward formalism of renormalization, applied to Quantum Electrodynamics. 3. **The BPHZ Formalism:** BPHZ-renormalization applied to scalar field theories. 4. **The Renormalization Group Equations:** Callan-Symanzik equations and their consequences; anomalous dimensions. 5. **Collinear Factorization an Evolution Equations:** collinear factorization of structure functions at twist 2, evolution equations for the parton distribution functions and Wilson coefficients and their analytic solution in the singlet and non-singlet cases; scheme-invariant evolution of observables. 6. **Hopf Algebras and Renormalization:** Hopf algebra structure as a tool to organize renormalization; mathematical foundations + examples. 7. **Renormalization of massive QCD with local operators:** mass, coupling, composite operator renormalization and collinear-factorization to higher loop order, different schemes.					
4	**Learning outcome** Students will gain initial insights into fundamental aspects of renormalization of relativistic quantum field theories of the various parts of the Standard Model of elementary particles from problem definition to the building blocks for concrete calculations.					
5	**Examination** Module examination: Graded oral examination (30 min)					
6	**Participation requirements**					
7	**Module type** Elective module					
8	**Responsible** Prof. J. Blümlein			**Faculty in charge** Department of Physics		

Module: Introduction to Grand Unified Theories (**PHY835**)				
Degree Program: Physics (M.Sc.)				
Frequency: As needed	**Duration:** Block course	**Semester:** 1st/2nd sem.	**Credits** 2	**Work load** 60 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	2	14 h block
2	**Language: English**				
3	**Content** 1. **The Structure of the Standard Model:** principle mathematical structure of the SU(3) x SU(2) x U(1) theory and its fermionic and bosonic sector; spontaneous symmetry breaking; ABJ-anomaly; running couplings and masses in the SM. 2. **The SU(5) Grand Unified Theory:** Structure of the gauge sector; specific choice of fermion representations; interaction terms; the different breaking formalisms and the Higgs-boson spectrum; mass pattern at large scales; running couplings and masses; coupling unification, mass ratios, proton decay, neutron-antineutron oscillation, baryon number asymmetry; SU(5) with new additional fermions. 3. **Main Aspects of the SO(10) Grand Unified Theory:** Extended fermion representations; Yukawa terms; neutrino mass; breaking formalisms; phenomenological aspects: proton lifetime, running of couplings; even higher GUTs. 4. **Monopoles:** Dirac monopoles; monopole solution of GUTs. 5. **Axions:** The strong CP problem; PQ solutions and their generalization in GUTs; particle phenomenology and present search limits.					
4	**Learning outcome** Students will gain initial insights into the concepts of grand unification (GUTs) of fundamental interactions and of fermion representations in the main GUTs. After a compact mathematical presentation of the Standard Model, the structures of the GUTs are discussed in terms of their boson and fermion structure and symmetry breaking, and important further phenomena are considered and a number of key experimental predictions are derived.					
5	**Examination** Module examination: Graded oral examination (30 min)					
6	**Participation requirements** Previous attendance of Group Theory module					
7	**Module type** Elective module					
8	**Responsible** Prof. J. Blümlein		**Faculty in charge** Department of Physics		

Module: Introduction to Group Theory and Lie Algebras (**PHY836**)				
Degree Program: Physics (M.Sc.)				
Frequency: In SS	**Duration:** Block course	**Semester:** 1st/2nd sem.	**Credits** 2	**Work load** 60 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	2	14 h block
2	**Language:** English				

3 Content

1. **Discrete Groups:**
   Permutation group, simple point groups.
2. **General Treatment of Lie Algebras:**
   Cartan basis, roots and root vectors, quantization; complete classification of all semi-simple Lie-groups, Dynkin representation.
3. **Young Tableaux:**
   general formalism, special calculations for several groups.
4. **Shuffle Algebras:**
   Algebraic relations in special function spaces of multi-iterated integrals and nested sums, occurring in Feynman diagram calculations; mathematical properties, computer-algebraic representations.
5. **The Poincare Group:**
   Lorentz transformations; structure of the group; massive and massless representations.

4 Learning outcome

Students gain initial insights into some methods of group theory and theory of algebras in physics, the structure of important groups, systematic classifications, a number of methods of representation and computation, and applications, including in the case of relativistic physics and elementary particle physics.

5 Examination

Module examination: Graded oral examination (30 min) or written exam depending on the Number of participants.

6 Participation requirements

7 Module type

Elective module

8	**Responsible** Prof. J. Blümlein	**Faculty in charge** Department of Physics

Module: Calculation Methods for Feynman Diagrams (**PHY837**)				
Degree Program: Physics (M.Sc.)				
Frequency: As needed	**Duration:** Block course	**Semester:** 1st/2nd sem.	**Credits** 2	**Work load** 70 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours**
	1	Lecture	L	2	14h block
	2	Exercise	T		4 h block
2	**Language:** English				

3 Content

1. **Feynman parameterization, D-dimensional integrals:**
   Parameterization of Feynman integrals, momentum integrals in D-dimensional space time; associated calculation methods.
2. **The one-loop integrals:**
   The representation of Feynman integrals through scalar N-point functions and their mathematical structure.
3. **Integration-by-parts reduction:**
   Reduction of Feynman integrals to master-integrals using Gauss' theorem.
4. **Hypergeometric integration, Mellin-Barnes integrals:**
   Solutions of Feynman integrals/ master intergrals using hypergeometric functions and their generalizations; analytic solutions through Mellin-Barnes representations.
5. **The method of differential equations:**
   Analytic solution of 1st order factorizing systems, including of associated difference equation systems.
6. **Special functions for Feynman integrals:**
   Multiply nested sums and iterated integrals over general alphabets; polylogarithms, multiple polylogarithms, cyclotomic polylogarithms, root-valued iterated integrals; harmonic sums, generalized sums and their further generalization; analytic continuation to complex arguments; associated special numbers.
7. **Non-first order factorizing systems:**
   2nd order differential equations and elliptic solutions; iterated non-iterative integrals; elliptic polylogarithms; meromorphic modular forms.

Exercise:
Computer-algebraic exercises of a series of formalisms, using FORM and Mathematica.

4 Learning outcome
Students are introduced to modern computational methods for Feynman diagrams, the associated mathematical function spaces, and computer algebraic methods.

5 Examination
Module examination: Graded oral examination (30 min)

6 Participation requirements

7 Module type
Elective module

8	**Responsible** Prof. J. Blümlein	**Faculty in charge** Department of Physics

Module: Theory of Soft and Biological Matter II (**PHY838**)				
Degree Program: Physics (M.Sc.)				
Frequency: As needed	**Duration:** 1 semester	**Semester:** 2nd sem.	**Credits** 5	**Work load** 150 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture and exercise	L+T	5	2 + 1
2	**Language:** English				
3	**Course content** Advanced topics in soft and biological matter: in particular, theoretical models for membranes, cytoskeleton, proteins, motor proteins, protein filaments. 1. **Membranes:** bending energy, liquid vesicle shapes, thermal fluctuations. 2. **Stochastic dynamics:** Brownian motion, diffusion problems, random walk, Markov processes, Langevin equation and Fokker-Planck equation. 3. **Physical and chemical kinetics:** thermally activated processes, chemical equilibrium, chemical kinetics, Michaelis-Menten. 4. **Biological physics:** molecular motors, filaments, ATP-driven processes. 5. **Nonlinear dynamics:** nonlinear mathematical models biological processes, reaction-diffusion processes, pattern formation, Turing instabilities.				
4	**Learning outcome** Students will be able to apply the modern methods of theoretical physics (from the areas of statistical physics, stochastic dynamics, nonlinear dynamics) to systems of soft matter and biological physics in an interdisciplinary manner. In exercises, students learn to independently grasp problems from the interdisciplinary subject area of soft matter as a theoretical-physical problem, to solve them and to discuss them in the group.				
5	**Examination** Course work: Exercises. Module examination: Graded written exam (120min) or oral exam (30 min), will be announced at the beginning of the course.				
6	**Participation requirements** Recommended: Theory of soft and biological matter 1. part				
7	**Module type** Elective module				
8	**Responsible** Prof. J. Kierfeld		**Faculty in charge** Department of Physics		

Module: Advanced Methods in Theoretical High-Energy Physics (**PHY839**)				
Degree Program: Physics (M.Sc.)				
Frequency: By the semester	**Duration:** Block course	**Semester:** 5th/6th sem.	**Credits** 2/3	**Work load** 60/90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	2/3	14h/ 22h Block
	2	Optional: Exercise session	T	1	4h/ 6h Block
2	**Language:** English				
3	**Course content** The block course is held by an external lecturer from a subfield of theoretical high-energy physics with expertise in, e.g., quantum field theory, physics beyond the standard model, or theoretical Astro-partivle physics and cosmology. The concrete topics covered vary. The students are introduced to theoretical concepts and frameworks relevant for state-of-the-art research in high-energy physics closely related to the current research and master-thesis projects at the HET groups of the TUDo. These include the topics of Non-abelian Gauge Theories, Renormalisation, Effective Field Theories Within and Beyond the Standard Model, Conformal Field Theories, Supersymmetry, Models of Adymptotic Safety, Early Universe and Baryogenesis.				
4	**Learning outcome** Students obtain a first in-depth contact with a concrete topic of high-energy physics with emphasis on theoretical methods and applications related to state-of-the-art research in theoretical high-energiy physics preparing them for a master-thesis project at the HET groups of the TUDo.				
5	**Examination** Module examination: written or oral depending on number of participants				
6	**Participation requirements** Physics IV and Advanced Quantum Mechanics (Theoretical Particle Physics or Quantum Field Theory useful.)				
7	**Module type** Elective module				
8	**Responsible** Prof.G. Hiller Prof. H. Päs Prof. E. Stamou	**Department in charge** Department of Physics			

Module: Renormalization in Theoretical High-Energy Physics (**PHY8310**)				
Degree Program: Physics (M.Sc.)				
Frequency: As needed	**Duration:** 1 Semester	**Semester:** from 2nd Semester	**Credits** 3	**Work load** 90 h

1	**Module Structure:**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture with integrated exercise	L + T	3	2
2	**Language:** english				
3	**Content** This lecture is a hands-on introduction to the topic of renormalization in high-energy physics. Topics include: loop computations, UV divergencies, regularization techniques, renormalization schemes, dimensional regularization, renormalization group equations, Callan-Symmanzik equation, dimensional transmutation, quantum triviality, Landau poles, asymptotic freedom and safety, critical phenomena, examples of fixed points.				
4	**Learning outcome** Students are familiar with regularization and renormalization techniques, and can apply them to UV divergencies encountered in loop calculations. The concept of the renormalization group and many phenomena, including critical points are understood.				
5	**Examination** Module exam: oral examination (30 min)				
6	**Participation Requirements** Recommended Courses: Quantum Field Theory, Introduction to Theoretical Elementary Particle Physics				
7	**Module type** Elective module				
8	**Responsible** Prof. G. Hiller		**Faculty in charge** Department of Physics		

Module: Seminar: Modern Quantum Computing and Quantum Simulation (PHY8311)				
Degree Program: Physics (M.Sc.)				
Frequency: As needed	**Duration:** 1 Semester	**Semester:** 1st/2nd Semester	**Credits** 3	**Work load** 90 h

1	**Module Structure:**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	S	3	2
2	**Language:** english				
3	**Content** • Feynman's Vision of Quantum Simulation • Universal Quantum Computers • Fundamental Algorithms • Modern Digital Quantum Simulations • Quantum Error Correction • Physical Realization of Quantum Gates • Topological Quantum Computation • Quantum Supremacy/Advantage				
4	**Learning outcome** Students will gain insights into the foundational works of quantum computing and digi-tal quantum simulations. The students work independently on a closely circled topic using one or two research articles. The aim of the seminar is for the students to pre-sent their gained knowledge and thereby expand the presentation techniques.				
5	**Examination** Module exam: oral presentation				
6	**Participation Requirements** Basic knowledge on quantum physics and quantum computing.				
7	**Module type** Elective module				
8	**Responsible** JProf. B. Fauseweh		**Faculty in charge** Department of Physics		

Module: Introduction to the clinical application of magnetic resonance imaging (**PHY8214**)				
Degree Program: Physics (M.Sc.)				
Frequency: annual	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture (1h)	L	6	4
	2	Exercise Session (1h)	T		
	3	Seminar (1h)	S		
	4	Clinical Training (1h)	P		
2	**Language:** English				

3 Content

In addition to classic nuclear medicine imaging procedures (PET, SPECT and scintigraphy) and X-ray-based procedures (X-ray diagnostics and computed tomography), which are used invasively or minimally invasively in the clinic, there are efforts to use minimally invasive or even non-invasive non-ionizing methods (ultrasound and magnetic resonance imaging, MRI) as imaging procedures to answer various clinical questions in order to avoid undesirable health side effects for patients and staff.
With its multidimensional and multicontrast techniques, MRI provides both morphological and functional information about a disease under investigation. MRI therefore plays an important role in diagnostics compared to the aforementioned procedures.
The focus of this four-part course is on 1) the physical basics of MRI, 2) the simulation of physical MRI techniques and the quantitative analysis of MRI images using various programming languages. 3) conducting a scientific literature search and preparing a scientific presentation, and 4) practical experience with various MRI techniques and image artifacts that can be used or occur during a clinical examination.

Literature:

- Mona Salehi Ravesh; Lecture notes, TU Dortmund University, 2023.
- Bernstein M. et al; "Handbook of MRI pulse sequences", Academic Press
- Haacke M. et. al.; "Magnetic Resonance Imaging: Physical Principle and Sequence Design", Wiley
- Schlegel W. et. al.; "Medical Physics", Springer
- www.pubmed.org
- https://mriquestions.com/index.html

4 Learning outcome

The lecture covers the basics of magnetic resonance imaging (Bloch equations, T_1, T_2, T_2^* weighting, slice selection, frequency and phase coding, k-space), which are necessary for understanding the MRI techniques used to characterize the tissue of various body organs and for vascular imaging (angiography) in any region of the body.
Through exercises, students will understand the mechanism of these techniques through simulations that they will implement themselves in a programming language of their choice.
During a seminar, students will be able to extract the essence of selected research articles and present recent advances in the clinical application of minimally invasive/non-invasive MRI techniques for whole-body tissue characterization and angiography. This will provide students with hands-on experience and develop their presentation skills, which are essential for future research activities and international conferences.
As part of a subsequent practical course, students will be able to carry out in vitro (phantom) examinations on a human MRI device, which will give them practical experience of the techniques and image artifacts covered in this course. In addition, they will gain their first

	experience in making a phantom that can be used for a specific question (susceptibility artifacts or relaxometry). This will give students practical experience and develop their decision-making skills, which are essential for future research activities.	
5	**Examination** Course credit: Active participation in the exercises, 20-minute seminar presentation, 2-3-page practical report. Module exam: oral exam (30 min)	
6	**Participation requirements**	
7	**Module type** Elective module	
8	**Responsible** PD Dr. M. Salehi Ravesh	**Faculty in charge** Department of Physics

Modul: Quantitative Magnetresonanztomographie: von Spinanregung zum Bild (**PHY8215**)					
PHY8215	**Credits** 6 CP	**Workload** 180 h	**Semester** 5./6. Semester	**Turnus** 1x jährlich	**Dauer** 1 Semester
Lehrveranstaltungen a) Vorlesung *Quantitative Magnetresonanztomographie: von Spinanregung zum Bild* b) Übung zu *Quantitative Magnetresonanztomographie: von Spinanregung zum Bild* c) Seminar zu *Quantitative Magnetresonanztomographie: von Spinanregung zum Bild* d) Praktikum zu *Quantitative Magnetresonanztomographie: von Spinanregung zum Bild*			**Kontaktzeit** a) 43 h b) 4 h c) 8 h d) 5 h	**Selbststudium** 90 h	**Gruppengröße** Studierende a) 15

Teilnahmevoraussetzungen
Formal: keine
Inhaltlich: Kenntnisse aus den Lehrveranstaltungen der „Theoretischen Physik II" und „Experimentalphysik III" sind erwünscht, aber sie sind nicht zwingend erforderlich für das Verständnis der Themen im Rahmen dieser Lehrveranstaltung.
Vorbereitung: keine

Lernziele (learning outcomes)
Nach dem erfolgreichen Abschluss des Moduls

- können Studierende im Rahmen von Übungen selbst in einer Programmiersprache ihrer Wahl mathematisch-physikalische Methoden implementieren, die zur quantitativen Analyse der behandelten MRT-Methoden in der Vorlesung eingesetzt werden. Im Rahmen eines Seminars können die Studierenden die Essenz ausgewählter Forschungsartikel extrahieren und die jüngsten Fortschritte bei der Anwendung von quantitativen MRT-Techniken zur humanen Bildgebung vorstellen. Hierdurch erhalten die Studierenden praktische Erfahrungen und entwickeln ihre Präsentationsfähigkeiten, die für zukünftige Forschungsaktivitäten und internationale Konferenzen unerlässlich sind....
- haben Studierende die Möglichkeit an einem humanen MRT-Gerät in-vitro (Phantom)-Untersuchungen durchführen, wodurch sie die behandelten Techniken und die Bildkontraste im Rahmen dieses Kurses praktisch kennenlernen werden. Zusätzlich werden sie die erste Erfahrung bei der Herstellung eines Phantoms sammeln, das für eine bestimmte Fragestellung (quantitative Relaxometrie) benutzt werden kann. Hierdurch erhalten die Studierenden praktische Erfahrungen und entwickeln ihre Entscheidungsfähigkeiten, die für zukünftige Forschungsaktivitäten unerlässlich sind.

Inhalt
Die Magnetresonanztomographie (MRT) ist ein nichtionisierendes bildgebende Verfahren. Das MRT ermöglicht multidimensionale (2D, 3D, 4D,...) und multikontraste (T_1-, T_2, T_2*, Diffusion, Perfusion, Suszeptibilität,...) in-vivo (human oder Tiere) oder ex-vivo (forensisch, verschiedene Substanzen, Zellkultur) Bildgebung entweder unter Verwendung von exogenen Kontrastmitteln oder mit Hilfe von endogenen Substanzen (Blut, Gewebebestandteile).

Die Fehlerfreie Zusammenstellung von verschiedenen Hardware- und Software-Komponenten basierend auf physikalischen und Mathematischen Prinzipien erlaubt die

Entstehung eines MRT-Bildes, das sowohl für wissenschaftlichen Zwecke als auch für die Diagnostik verwendet werden kann. Die MRT-Bilder können entweder qualitativ oder quantitativ bewertet werden. Eine quantitative Bewertung ermöglicht sowohl eine objektive Beurteilung der MRT-Bilder unabhängig von fachlicher Erfahrung des Anwenders als auch den Einsatz von entsprechenden MRT-Methoden im Rahmen der Langzeituntersuchungen sowie medikamentösen Behandlungen.

Die Foki dieser vierteiligen Lehrveranstaltung liegen in 1) dem Verständnis der Entstehung verschiedener Bildkontraste aus physikalischer Hinsicht, 2) Analyse von quantitativen MRT-Aufnahmen mittels verschiedener Programmierungssprachen, 3) Vorbereiten einer wissenschaftlichen Präsentation über ein MRT-relevantes Thema basierend auf aktueller Literatur sowie, 4) der praktischen Erfahrung mit den MRT-Techniken und -Kontrasten, die im Rahmen der Vorlesung vorgestellt werden.

Literatur:

- Mona Salehi Ravesh; Vorlesungsskript, TU Dortmund, 2024.
- Bernstein M. et al.; „Handbook of MRI pulse sequences“, Academic Press
- Haacke M. et. Al.; „Magnetic Resonance Imaging: Physical Principle and Sequence Design“, Wiley Verlag
- Schlegel W. et. Al.; „Medizinische Physik“, Springer Verlag
- www.pubmed.org
- https://mriquestions.com/index.html

Lehrformen: Vorlesung, Übung, Seminar, Praktikum

Prüfungsformen (falls das Modul in einem Schwerpunktbereich gewählt wird)
Studienleistungen: Aktive Teilnahme an Übungen, Seminar und MRT-Praktikum.
Modulprüfung: 20-minütige schriftliche Prüfung (Multiple choice) oder mündliche Prüfung (30 Minuten)

Prüfungsformen (falls das Modul im Grundlagen- und Wahlbereich gewählt wird)
Studienleistungen: Aktive Teilnahme an Übungen, Seminar und MRT-Praktikum.
Modulprüfung: 20-minütige schriftliche Prüfung (Multiple choice) oder mündliche Prüfung (30 Minuten)

Voraussetzungen für die Vergabe von Kreditpunkten Bestehen der Prüfungsleistungen

Verwendung des Moduls

Modulbeauftragte/r PD habil. Dr. rer. nat. Mona Salehi Ravesh

Sonstige Informationen Diese Modul wird an der TU Dortmund angeboten.

Module: Ultrafast spintronics and light driven magnetisation dynamics (PHY8216)				
Degree program: Physics (B.Sc. and M.Sc.)				
Frequency Annually in SS	**Duration** 1 Semester	**Semester** 1^{st} – 4^{th} semester (M. Sc.) from 5^{th} semester (B. Sc.)	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	S	3	2
2	**Language:** English				
3	**Content** Contemporary topics in light-field driven electron spin, orbital and/or magnetisation manipulation on ultrafast timescales, including areas such as ultrafast magnetisation dynamics in ferro- and antiferromagnetic systems, light-field driven spin current generation, ultrafast magneto-resistive effects in magnetic heterostructures, spintronic terahertz frequency harmonic generation, nonlinear regime of magnetisation dynamics, spintronic terahertz emission spectroscopy, ultrafast magneto-optical effects.				
4	**Learning outcome** Students will gain an understanding of the modern problems of ultrafast spintronics, including fundamental and experimental aspects of electron spin, orbital, and/or magnetisation manipulation with light. In their own presentations, students will learn how to present scientific material in an understandable way and how to participate in scientific discussions.				
5	**Examination** Performance: active participation in the seminar presentations and discussions. Module examination: Graded own presentation (30 minutes + 15 minutes discussion)				
6	**Forms of examination and performance** ☒ **Module examination: oral exam** ☐ **Partial performance**				
7	**Prerequisites** Knowledge in optics and introductory condensed matter physics				
8	**Module type** Elective module				
9	**Responsible** Dr. S. Kovalev Prof. Z. Wang	**Organization** Department of Physics			

Module: Dark Matter and Axions (**PHY8217**)				
Degree Program: Physics (M.Sc.)				
Frequency: in SS	**Duration:** 1 semester	**Semester:** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	S	3	2
2	**Language:** English				
3	**Content** The content of the seminar is the search for new particles that could compose the dark matter. We will primarily examine axions as candidates, while also covering Weakly Interacting Massive Particles (WIMP), with an emphasis on current experimental approaches and results. These experimental approaches can be ground-based, either in experiments above ground or in underground laboratories, as well as space-based, utilizing observatories from NASA, ESA, and JAXA.				
4	**Learning outcome** Students deepen their knowledge in the field of the seminar through self-study on their own presentation. This lecture also trains competencies in scientific literature research and presentation techniques. In the subsequent discussion, scientific discussion techniques are acquired.				
5	**Examination** Course Credits: Active participation in the discussions following the lectures. Module examination: Graded own presentation.				
6	**Participation Requirements**				
7	**Module type** Elective module				
8	**Responsible** Prof. J. Vogel, Dr. J. Ruz Armendáriz		**Faculty in charge** Department of Physics		

Module: Quantum Information (From Qubits to Black Holes) **(PHY7318)**				
Degree Program: Physics (M.Sc.)				
Frequency: As needed	**Duration:** 1 Semester	**Semester:** 1st/2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	2
2	**Language:** English				
3	**Content** QM Recap, Computing & Church-Turing Thesis, Quantum Computing: Qubits, Circuits, Gates & Entanglement, Quantum Dense Coding & Quantum Teleportation, Quantum Algorithms, Complexity, Decoherence & Quantum Error Correction, Experimental Realizations, Cryptography & Quantum Money, Quantum Information, Black Holes & Emergent Spacetime, Quantum Information & QFT				
4	**Learning outcome** Students gain an insight into the basics of quantum information and quantum computing, such as Qubits, density matrices, entanglement, quantum circuits and gates, quantum error correction, including recent applications such as quantum computing and black holes information processing.				
5	**Examiation** Graded written or oral exam				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Prof. H. Päs		**Faculty of charge** Department of Physics		

<table>
<tr><td colspan="6">Module: Modern Quantum Computing and Quantum Simulation (PHY7319)</td></tr>
<tr><td colspan="6">Degree program: Physics (M.Sc.)</td></tr>
<tr><td colspan="2">Frequency:
in SS</td><td>Duration:
1 Semester</td><td>Semester:
1st/2nd sem.</td><td>Credits
6</td><td>Work load
180 h</td></tr>
<tr><td rowspan="3">1</td><td colspan="5">Module structure</td></tr>
<tr><td>No.</td><td>Element / Course</td><td>Type</td><td>Credits</td><td>Contact hours per week</td></tr>
<tr><td>1</td><td>Lecture</td><td>L + T</td><td>6</td><td>3+1</td></tr>
<tr><td>2</td><td colspan="5">Language: English</td></tr>
<tr><td>3</td><td colspan="5">Content
Part 1:
Basics of Quantum Information Theory and Processing, Qubits, Gates, Quantum Circuits, POVMs, Solovay-Kitaev Theorem, Tomography, Mixed States, Entanglement (bipartite and multi-partite), Fisher Information, Algorithms (Deutsch–Jozsa, QFT, Digital Quantum Simulation, Grover, Shor, Harrow–Hassidim–Lloyd, Quantum Singular Value Transformation), Elements of Quantum Complexity Theory

Part 2:
Selected Topics of: Noise and Decoherence, Noise Learning, Error Correction, Hybrid Quantum Classical Methods, Adiabatic Quantum Computing & Annealing, Variational Algorithms, Parameter Shift Rules, Quantum Machine Learning, Barren Plateaus, Quantum Natural Gradient, Fermionic to Qubit Mappings (Jordan-Wigner, Tree-based mappings), Error Mitigation, Programming on Modern Quantum Computing Platforms, Random Quantum Circuits & Monitored Dynamics, Measurement-Based Quantum Computing</td></tr>
<tr><td>4</td><td colspan="5">Learning outcome
Students get a comprehensive overview of quantum information theory, such as qubits, gates, circuits, entanglement, algorithms, and complexity theory as well as an introduction into the current research topics of the noisy intermediate scale quantum era, such as decoherence, error correction, hybrid approaches, quantum machine learning and programming modern quantum computing platforms.</td></tr>
<tr><td>5</td><td colspan="5">Examination
Graded written or oral exam</td></tr>
<tr><td>6</td><td colspan="5">Participation requirements</td></tr>
<tr><td>7</td><td colspan="5">Module type
Elective Module</td></tr>
<tr><td>8</td><td colspan="2">Responsible
JProf. B. Fauseweh</td><td colspan="3">Faculty of charge
Department of Physics</td></tr>
</table>

Module: Ultrafast Spectroscopic Methods in Solid State Physics (**PHY7236**)				
Degree program: Physics (M.Sc.)				
Frequency in SS	**Duration** 1 Semester	**Semester** 1st – 4th semester	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	2
2	**Language:** English				
3	**Content** 1. **Excitation techniques:** generation of femtosecond and attosecond laser pulses, ultrafast laser amplifier systems, optical parametric amplifier, laser- and accelerator-based infrared and THz sources. 2. **Probing techniques:** electro- and magneto-optic sampling, transient reflection or absorption spectroscopy, Fourier transform infrared spectroscopy, Raman spectroscopy, THz emission spectroscopy, high harmonic generation spectroscopy, time-resolved angular resolved photoemission spectroscopy, ultrafast electron diffraction spectroscopy. **3. Examples:** ultrafast magnetization dynamics, high harmonic generation, light induced spin or charge transport dynamics etc.				
4	**Learning outcome** Students gain insight into modern techniques of time-resolved ultrafast or nonlinear spectroscopy, together with examples of their implementation in recent solid-state physics research.				
5	**Examination** Module examination: Graded oral examination (30 min)				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Dr. S. Kovalev, Prof. Z. Wang			**Faculty in charge** Department of Physics	

Module: Condensed matter physics: Time-domain Terahertz spectroscopy (**PHY7237**)				
Degree program: Physics (M.Sc.)				
Frequency As needed	**Duration** 1 Semester	**Semester** 1st/2nd sem.	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture	L	3	2
	2	Exercise	T	3	2
2	**Language:** English				

3 **Content**

Lecture

1. **Introduction:**
   optical response functions, Maxwell equations in matter
2. **Charge carrier transport:**
   2.1. Drude model
   2.2. DC conductivity
   2.3. AC conductivity
3. **Terahertz technology**
   3.1. General introduction
   3.2. Generation of sub-picosecond Terahertz pulses
      3.2.1. Terahertz pulse generation by photoconductive switches
      3.2.2. Terahertz pulse generation in gas plasma
      3.2.3. Terahertz pulse generation by optical rectification
   3.3. Time-resolved detection of Terahertz pulses: Photoconducting dipole antennas and electro-optic sampling
4. **Introduction to multidimensional Terahertz spectroscopy**
   4.1. Introduction to nonlinear optics
   4.2. Liouville Pathway diagrams
   4.3. Case of semiconductors
   4.4. Case of liquid water
   4.5. Case of magnetic materials

Exercise

The exercise session serves first as in depth hands-on introduction of the complex experimental setup to the students. In particular, the students will have the chance to see the different state-of the-art technique at work and how to use them to perform real experiments in the laboratory. In addition, this session will be dedicated to show to the student how to analyze the experimental data. At the end, the experimental part will allow the students to:

- Understand the water vapor absorption lines in the terahertz regime using THz-TDS spectroscopy.
- Measure the terahertz transmission of a Silicon substrate and find the thickness of the substrate from the time domain signals.
- Determination of the complex refractive index of semiconductors (Silicon, GaAs, Germanium, ...) and liquid solution (water, isopropanol, methanol, ...)

4 **Learning outcome**

The students will acquire basic interdisciplinary knowledge in the field of time-domain and multidimensional Terahertz spectroscopy. They will be able to measure and analyze a Terahertz spectrum, for instance obtaining the thickness and calculating the refractive

	index of a sample. After the successful completion of the course, students are expected to have an overview about nonlinear multidimensional terahertz spectroscopy	
5	**Examination** Course work: Active participation in the lecture and the exercise session. Examination: Graded oral examination (lecture) and graded written final report (exercise session)	
6	**Participation requirements**	
7	**Module type** Elective module	
8	**Responsible** Dr. A. Ghalgaoui, Prof. Z. Wang	**Faculty in charge** Department of Physics

Module: Advanced Laboratory Course II: Solid State Physics (**PHY842**)				
Degree program: Physics (M.Sc.)				
Frequency: in SS	**Duration:** 1 semester	**Semester:** 2nd semester	**Credits** 6	**Work load** 180h

1	**Module structure** 4 contact hours per week, laboratory course; experiments are performed in small groups, and supervised by experienced scientists.	
2	**Language:** English	
3	**Content** In the optional second part of the advanced laboratory course, students are given the opportunity to focus thematically. The module with the focus on solid state physics usually consists of 5 experiments in this area. For this purpose, more advanced experiments are offered from the area of the classical advanced practical course. Examples are the experiments on the Faraday effect and X-ray reflectometry. Such experiments are then combined with lab experiments from the experimental solid state physics groups. Examples from this area are experiments on nonlinear and/or ultrafast optics on solids. By means of such experiments, the knowledge and skills acquired by the students from the practical courses of the bachelor's program are deepened and extended with respect to current techniques. The respective experiment instructions contain only a short outline of the theoretical and experimental basics, so that the required knowledge has to be acquired by self-study and the handling of English journals is learned. Accompanying the module, students are given the opportunity to give a seminar talk in a thematically related seminar and to acquire an additional 3 LP through active participation in the seminar. Literature: In addition to the instructions, self-study of the literature is necessary, e.g.: Bergmann, Schäfer, Textbook of Experimental Physics 1-6 Gross, Marx, Solid State Physics Provided journal articles	
4	**Learning outcome** The students are able to independently understand, perform and analyze complex experiments and to present the facts. They have learned to independently familiarize themselves with a topic (with English-language literature), as well as to select and apply a suitable method from various measurement techniques or analysis methods. Students have learned to troubleshoot and correct errors if necessary. Students are able to formulate and document a scientific work process and to critically discuss their results. They have learned to work in a team and to communicate with each other scientifically.	
5	**Examination** Course credits: Preparation, experimental performance and tested experimental protocols. Module examination: Graded oral examination (30 min).	
6	**Participation requirements**	
7	**Module type** Elective module	
8	**Responsible** Dean of the Department of Physics	**Faculty in charge** Department of Physics

Module: Advanced Laboratory Course II: Particle Physics (PHY843)				
Degree program: Physics (M.Sc.)				
Frequency in SS	Duration 1 semester	Semester 2nd semester	Credits 6	Work load 180 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Laboratory course in small groups	P	6	4
2	**Language:** English				
3	**Content** Students explore experimental techniques in particle physics in depth through approximately five specific experiments and approach advanced topics in the field. The techniques to be learned come from the areas of data analysis, simulation, and detector physics, among others. The concepts and background to these techniques and topics will be developed by the students themselves.				
4	**Learning outcome** Students will selectively explore experimental techniques and advanced topics and deepen their knowledge through hands-on experiments in the field.				
5	**Examination** Graded module examination.				
6	**Coursework and examination requirements** Coursework: Preparation and conduction of laboratory experiments including reports Module examination: oral examination (30 min.)				
7	**Participation requirements** Basic knowledge of particle physics				
8	**Module type** Elective module				
9	**Responsible** Dean of the Department of Physics	**Faculty in charge** Department of Physics			

Module: Advanced Laboratory Course II: Theoretical Course (**PHY844**)				
Degree Program: Physics (M.Sc.)				
Frequency: annual	**Duration:** 1 semester	**Semester:** 2nd sem.	**Credits** 6	**Work load** 180 h

1	**Module Structure:** 4 contact hours per week internship, project work usually in small groups	
2	**Language:** English	
3	**Content** The students deepen theoretical techniques in condensed matter or particle physics within the framework of a larger project by means of independent literature study and, based on this, their own analytical calculations or independently programmed simulations on advanced topics in these areas. Students thus learn advanced analytical methods or gain in-depth practical experience in scientific programming, especially in structuring larger programming projects. Accompanying the module, students are given the opportunity to give a seminar talk in a thematically related seminar and to earn an additional 3 CP through active participation in the seminar.	
4	**Learning outcome** Students are able to independently understand, apply and present complex analytical methods or simulation techniques. They have learned to familiarize themselves independently with a topic (on the basis of English-language literature) and to actively comprehend the latest theoretical methods.	
5	**Examination** Course achievement: Written elaboration Module examination: Graded oral examination (30 min)	
6	**Participation Requirements** Knowledge of solid-state theory or elementary particle theory	
7	**Module type** Elective module	
8	**Responsible** Prof. J. Kierfeld	**Faculty in charge** Department of Physics

Modules: Advanced Laboratory Course II: Electronics (**PHY845**)				
Degree program: Physics (M.Sc.)				
Frequency in SS	**Duration** 1 semester	**Semester** 2nd sem.	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Laboratory course in small groups	P	6	4
2	**Language:** English				
3	**Content** The students deepen basic concepts of electronics and apply them in practical exercises. The practical covers the areas of analog and digital electronics.				
4	**Learning outcome** The course introduces the fundamental elements of electronics, together with laboratory experiences. The student will acquire knowledge of the typical building blocks, components and methods of electronics. Using standard examples, he/she will be able to identify and characterize components in circuits. 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	**Examination** Coursework: Preparation and conduction of laboratory experiments including reports Module examination: Oral examination				
6	**Participation requirements**				
7	**Module type** Elective module				
8	**Responsible** Dean of the Department of Physics		**Faculty in charge** Department of Physics		

Module: Condensed Matter Theory Laboratory Course (**PHY846**)				
Degree Program: Physics (M.Sc.)				
Frequency: annual	**Duration:** 1 semester	**Semester:** 2nd sem.	**Credits** 3	**Work load** 90 h

1	**Module structure**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Self-study and own presentation	S	3	2
2	**Language:** English				
3	**Content** In the theoretical laboratory course (Module PHY844), students deepen their knowledge of theoretical techniques in condensed matter physics within the framework of a larger project by means of independent study of the literature and, based on this, their own analytical calculations or independently programmed simulations. Accompanying Module PHY844, students in this module are given the opportunity to give an English-language seminar presentation on their project. In doing so, the own work results from the theoretical laboratory course (Module PHY844) as well as their physical environment are to be presented in an English-language lecture.				
4	**Learning outcome** By preparing and giving their own presentation, they acquire skills in scientific methodology, especially in research and presentation techniques. A special goal is to train the view for the essentials of a physical problem.				
5	**Examination** Course Credits: Active participation in the discussions following the lectures. Module examination: Graded own oral presentation (30 min) on the project topic of the theoretical laboratory course (Module PHY844).				
6	**Participation Requirements** Participation in the theory course (Module PHY844) in condensed matter.				
7	**Module type** Elective module				
8	**Responsible** Prof. J. Kierfeld		**Faculty in charge** Department of Physics		

Module: English for Physics C1				
Degree program: Physics (M.Sc.)				
Frequency: in WS	**Duration:** 1 semester	**Semester:** 1st, 3rd semester	**Credits** 6	**Work load** 180h

1	**Module structure** 4 contact hours per week	
2	**Language:** English	
3	**Content** The course develops students' abilities to communicate orally and in writing, with an emphasis on scientific and technological topics relevant to physics. Upon successful graduation, students should be able to communicate in a professional setting, discuss topics related to physics, and disseminate science in academic and professional contexts. The course participants are invited to make their suggestions on discussion topics.	
4	**Learning outcome** The course trains the following competencies: • ability to understand written, audio, and audio-visual texts from a variety of authentic sources; • ability to provide logical descriptions of the phenomena related to their professional field; • ability to summarize and critically respond to scientific texts such as lectures, talks, and articles; • ability to integrate concept and process descriptions into their written texts and presentations; • ability to talk and write about their research activities and explain their ongoing work.	
5	**Examination** This is an integrated skills course. To graduate from the course, a student should demonstrate sufficient abilities in listening, reading, writing, speaking, and mediation. Graded certificate requirements: • listening-comprehension test (20%) • in-class presentation and a follow-up discussion (25%) • course portfolio (50%) • active participation (5%) • Selected assignments are collected and turned in as a course portfolio. The portfolio organizes and presents what students learned in the course and showcases their achievements.	
6	**Participation requirements** English B2 Permitted missing units: 8 units (1 unit corresponds to 45 minutes)	
7	**Module type** Elective module	
8	**Responsible** zhb	**Faculty in charge** zhb

Module: Thin film growth: From low-dimensional physics to industrial applications				
Degree program: Physics (M. Sc.)				
Frequency One-time (Ulrich Bonse Visiting Chair, WS 24/25)	**Duration** 1 Semester	**Semester** 1st/3rd semester	**Credits** 6	**Work load** 180 h

1	**Module structure**				
	No.	**Element / course**	**Type**	**Credits**	**Contact hours per week**
	1	Lecture + Exercise	L+T	6	4
2	**Language:** English				

3 Content

The lecture covers the fundamental physical mechanisms of crystalline growth of thin films on surfaces, the characterization of relevant properties both on-surface and at the device level, and the role of thin film engineering in applied electronics, magnetism and optics - ranging from solar cells, LEDs to transistors and MRAMs. The essential role of the interfaces between dissimilar materials will be outlined, connecting the concepts of (hetero)epitaxial growth with the measured physical properties. The choice of growth parameters to design low-dimensional materials with novel properties will be also highlighted, such as 2D electron gases, 2D magnetic materials, and topological semimetals.

Crystalline growth on surfaces- concepts: surface kinetics and thermodynamics, ultra-high vacuum, vapor phase deposition, physisorption and chemisorption, surface energy, sticking coefficient, nucleation, layer growth modes (layer-by layer, 3D growth)

Growth and surface characterization methods: molecular-beam epitaxy, pulsed laser deposition, magnetron sputtering, chemical vapor deposition, atomic layer deposition, reflection high energy electron diffraction (RHEED), low energy electron diffraction (LEED), scanning probe microscopy, X-ray photoelectron spectroscopy, X-ray absorption
Device characterization: I-V characteristics, electrical transport, electroluminescence, photoluminescence, thermal transport, transconductance, magnetoresistance, on-chip magnetic resonance, spin-transfer torque
Applications of thin films: Light-emitting diodes (LEDs and OLEDs), Solar cells (single and tandem), Field-effect transistors (FETs), Hard-disk drive (HDD) sensors, Magnetic Random Access Memories (MRAMs)
Literature:
- Bedoya-Pinto, K. Chang, M. Samant and S.S.P. Parkin, *Material Preparation and Thin Film Growth*, in Handbook of Magnetism and Magnetic Materials, Seiten 1153-1202, Springer International Publishing (2021)
- H.J Kreuzer, *Theoretical Approaches to Surface Kinetics: A Perspective*. Z. Phys. Chem.223, 105-129 (2009)
- Tsao, J.Y.: *Materials Fundamentals of Molecular Beam Epitaxy*, pp. 13-41. Academic Press, San Diego (1993)
- E. Acosta, *Thin film properties and Applications,* (2021) DOI: 10.5772/intechopen.95527

4	**Learning outcome** The lecture provides an overview of the mechanisms of crystalline growth on surfaces and the connection of growth parameters with the resulting physical properties of thin films and devices. Additionally, practical roadmaps to gear fundamental physics towards industrial applications will be exemplified with success stories from the thin film science community.
5	**Examination** **Module exam: written exam (120 min)**
6	**Forms of examination and performance** ☒ **Module examination: written** ☐ **Partial performance**
7	**Prerequisites** Classical Mechanics, Optics, Electrodynamics, Thermodynamics
8	**Module type** Elective module
9	**Responsible** Dr. Amilcar Bedoya-Pinto | **Department** Department of Physics

Strahlenschutzkurs

KM06	Credits 1 CP	Workload 30 h	Semester ab 1. Sem.	Turnus SoSe	Dauer 1 Semester

Lehrveranstaltungen	Kontaktzeit	Selbststudium	Gruppengröße
a) Vorlesung *Strahlenschutzkurs* b) Praktikum *Strahlenschutzkurs*	mind. 20 h mind. 4 h	mind.6 h	Max. 30

Teilnahmevoraussetzungen
Formal: keine
Inhaltlich: Mathematisch physikalische Grundkenntnisse aus dem Bachelor-Studiengang
Vorbereitung: keine

Lernziele (learning outcomes)
Die Studierenden haben die Kenntnisse erworben, wie sie von einem Strahlenschutzgrundkurs gemäß rechtlichen Vorschriften vermittelt werden.

Inhalt
Grundlagen: Strahlungsphysik, Radioaktivität, Strahlenbiologie, Dosimetrie, Bestrahlungsplanung. Dosisabschätzungen, Personendosimetrie.
Strahlenanwendung am Menschen: rechtfertigende Indikation
Natürliche und zivilisatorische Strahlenexposition.
Strahlschutz: Grundlagen, baulicher und apparativer Strahlenschutz, Anwendungen (z.B. in der Nuklearmedizin), Gesetzliche Grundlagen.

Lehrformen Vorlesung

Prüfungsformen (falls das Modul in einem Schwerpunktbereich gewählt wird) Erbringung einer Studienleistung. Die Studienleistung kann in Form eines schriftlichen Tests oder eines Gesprächs mit der/dem Lesenden erbracht werden.

Prüfungsformen (falls das Modul im Grundlagen- und Wahlbereich gewählt wird) Studienleistung: keine, Modulprüfung: wird zu Beginn der Veranstaltung bekanntgegeben

Voraussetzungen für die Vergabe von Kreditpunkten: Bestehen der Prüfungsleistungen

Verwendung des Moduls: Teil des Schwerpunktmoduls Klinische Medizinphysik

Modulbeauftragte/r Prof. Dr. Armin Lühr

Lehrende: Lühr, Block, sowie externes Lehrpersonal

Sonstige Informationen Bzgl. Beratung und Koordination der Veranstaltungen wenden Sie sich bitte an den Modulbeauftragten. Die Veranstaltung findet in deutscher Sprache und als Blockkurs statt.

Moderne Strahlentherapie

KM10	**Credits** 3 CP	**Workload** 90 h	**Semester** 1. Sem.	**Turnus** WiSe	**Dauer** 1 Semester
Lehrveranstaltungen a) Vorlesung zu *Moderne Strahlentherapie* b) Übung zu *Moderne Strahlentherapie*			**Kontaktzeit** a) 30 h b) 15 h	**Selbststudium** 45 h	**Gruppengröße**

Teilnahmevoraussetzungen

Formal: keine

Inhaltlich: keine

Vorbereitung: keine

Lernziele (learning outcomes)

Nach dem erfolgreichen Abschluss des Moduls können die Studierenden:

- Die verschiedenen modernen Bestrahlungstechniken wie Intensitätsmodulierte Strahlentherapie (IMRT), Volumetric Modulated Arc Therapy (VMAT), helikale Tomotherapie, Sterotaxie, Bildgef#hrte Strahlentherapie (IGRT), adaptive Strahlentherapie, Therapie mit geladenen Teilchen und Brachytherapie zur optimalen Krebsbehandlung und für verschiedene Tumorarten wissen.
- Die konzeptionellen Einsatzmöglichkeiten der Bildgebungsverfahren sowie in vivo Dosimetrieverfahren in den modernen Bestrahlungstechniken differenzieren.
- Das Risiko für sekundäre Tumore nach Strahlentherapie evaluieren.

Inhalt

Die Strahlentherapie ist vielfältig, und die Komplexität der Tumorbehandlung erfordert den Einsatz unterschiedlicher Strahlentherapie-Modalitäten sowie technischer Hilfsmittel, um optimale Behandlungsergebnisse zu erzielen. Die Veranstaltung bietet eine Einführung in die moderne Strahlentherapie:

- Bildgebende Verfahren in der Strahlentherapie (Wiederholung)
- Strukturerkennung, Segmentierung und Registrierung in der Strahlentherapie
- Stand der Technik der Photonentherapie
- Stereotaxie und Radiochirurgie
- Strahlentherapie mit geladenen Teilchen
- Zeitlich-räumliche Fraktionierung in Strahlentherapie
- FLASH-Therapie
- 4D-Strahlentherapie (für bewegliche Tumore)
- Adaptive Strahlentherapie
- MRT-basierte Strahlentherapie
- Boron-Neutronen-Einfangtherapie
- Brachytherapie und Intraoperativen Strahlentherapie
- Strahlentherapie für schwangere Patientinnen

Lehrformen Vorlesung, Praktikum

Prüfungsformen

Studienleistungen: aktive Mitarbeit

Modulprüfung: mündliche Prüfung oder Klausur

Voraussetzungen für die Vergabe von Kreditpunkten Bestehen der Prüfungsleistungen

Verwendung des Moduls Wahlmodul

Stellenwert der Note für die Endnote Gewichtung mit CP

Modulbeauftragte/r Dr. A. Hammi

Sonstige Informationen Dieses Modul wird an der TU Dortmund angeboten

Module: Research Internship (**PHY911**)				
Degree program: Physics (M.Sc.)				
Frequency: every semester	**Duration:** 1 semester	**Semester:** 3rd sem.	**Credits** 15	**Work load** 450 h

1	**Module structure** Research internship	
2	**Language:** English	
3	**Content** Literature research Familiarization with theoretical procedures or experimental procedures Discussion of problems of current research Preparation of a short (approx. 5 p.) report Literature: Current literature on the respective research area In addition, e.g. Ascheron, Kickuth: Make Your Mark in Science, Alley: The Craft of Scientific Presentation, Alley: The Craft of Scientific Writing.	
4	**Learning outcome** Students will be able to work independently in a current area of research with the associated experimental or theoretical methods. The students can summarize their work in a report. In addition to the technical deepening, the students have further developed their written presentation skills as well as their media skills and communication skills.	
5	**Examination** Graded written or oral short report	
6	**Participation requirements** 40 credit points earned in the master's degree program in physics	
7	**Module type** Mandatory module	
8	**Responsible** Dean of the Department of Physics	**Faculty in charge** Department of Physics

Module: Methods and Project Planning (**PHY912**)				
Degree program: Physics (M.Sc.)				
Frequency: every semester	**Duration:** 1 semester	**Semester:** 3rd sem.	**Credits** 15	**Work load** 450 h

1	**Module structure** Project planning for the master thesis Working group seminar: 2 contact hours per week Online Lecture in Good Scientific Practice	
2	**Language:** English	
3	**Content** Students define a scientific problem in consultation with their future supervisor and develop a project plan to solve the problem within a given time frame. They are introduced to basic project management methods and create, present and discuss the developed project plan. The online Course on Good Scientific Practice gives an introduction to the rules of good scientific practice and covers different aspects of misconduct in research and handling of conflicts, handling of research data, writing of qualification works and publications, authorship, subject-specific areas of responsibility of good scientific practice, the responsibility of supervisors and supervised students, conflicts of interest, scientific cooperation and science communication.	
4	**Learning outcome** Students will be able to formulate a current scientific problem and develop the work plan and timetable for successful completion of the independent research project as part of the master's thesis. In particular, they have further developed their methodological competence in the application of specialized knowledge as well as the ability to write scientifically. In the course of good scientific practice, students acquire basic professional competencies to understand the fundamentals of good scientific practice in general and in relation to the topics mentioned above. They acquire initial action competencies to apply the rules of good scientific practice to their academic field.	
5	**Examination** Graded project work, e.g., research plan and methods overview. Online quiz or oral exam (not graded) for the part on good scientific practice	
6	**Participation requirements** 40 credit points earned in the master's degree program in physics	
7	**Module type** Mandatory module	
8	**Responsible** Dean of the Department of Physics	**Faculty in charge** Department of Physics

Module: Particle physics meets industry (**PHY921**)				
Degree Program: Physics (M.Sc.)				
Frequency: in SS and WS	**Duration:** 1 semester	**Semester:** 3rd/4th sem.	**Credits** 3	**Work load** 90 h

1	**Module Structure:**				
	No.	**Element / Course**	**Type**	**Credits**	**Contact hours per week**
	1	Seminar	S	3	2
2	**Language:** English				
3	**Content** The seminar is aimed at Master's students who have specialized in particle physics (or related fields) and who are about to complete their Master's degree. The aim of the seminar is to bridge the gap between university education and industry, and to foster the dialog between students and practitioners. We will invite former (particle) physics students, e.g., from the IMAPP program, industry contacts or non-academic collaborators, to present their work as physicists in industry, business or management, to explain how they entered the labor market, and to discuss which of the skills and competences they learned during their university education have proven useful. Students will also be introduced to research opportunities in industry, e.g., as potential future employees or for doctoral studies. The presentations will be supplemented by a selection of material that will provide orientation for a possible transition from university to industry.				
4	**Learning outcome** Students will obtain an overview of different areas of work. They will understand different paths on how to enter the labor market and learn about the requirements on the skill sets needed for different industries. The students will evaluate their competences with regard to these requirements and explore additional offers by the university and elsewhere to improve them. At the end of the course, students will be able to compare their interests and skills with the requirements of a representative selection of professions.				
5	**Examination** Course work: Active participation in the discussions following the presentations. Module exam: Graded summary report				
6	**Participation Requirements** %				
7	**Module type** Elective module				
8	**Responsible** Prof. K. Kröninger	**Faculty in charge** Department of Physics			

Module: Master’s thesis (**PHY1011**)				
Degree program: Physics (M.Sc.)				
Frequency: every semester	**Duration:** 6 months	**Semester:** 4th Sem.	**Credits** 30	**Work load** 900 h

1	**Module structure** Supervised research	
2	**Language:** English	
3	**Content** Work on a current scientific problem in experimental or theoretical physics in an international research environment and final presentation of the results. Literature: Monographs, review articles and original publications on the respective scientific problem.	
4	**Learning outcome** The students are able to work independently on a current scientific project in an international research environment in accordance with a project plan they have developed, i.e. carry out the corresponding experiments or calculations. In addition to the technical competence required for the research project, the students will have developed their methodological competence, team competence, communication competence, oral presentation skills, self-competence (ability to work under pressure, flexibility, time management) and often also intercultural competence.	
5	**Examination** Course achievement: presentation of research results in a lecture. Graded module examination: Assessment of the master's thesis with regard to content and form.	
6	**Participation requirements** Module "Methods and Project Planning" (PHY912)	
7	**Module type** Mandatory module	
8	**Responsible** Dean of the Department of Physics	**Faculty in charge** Department of Physics