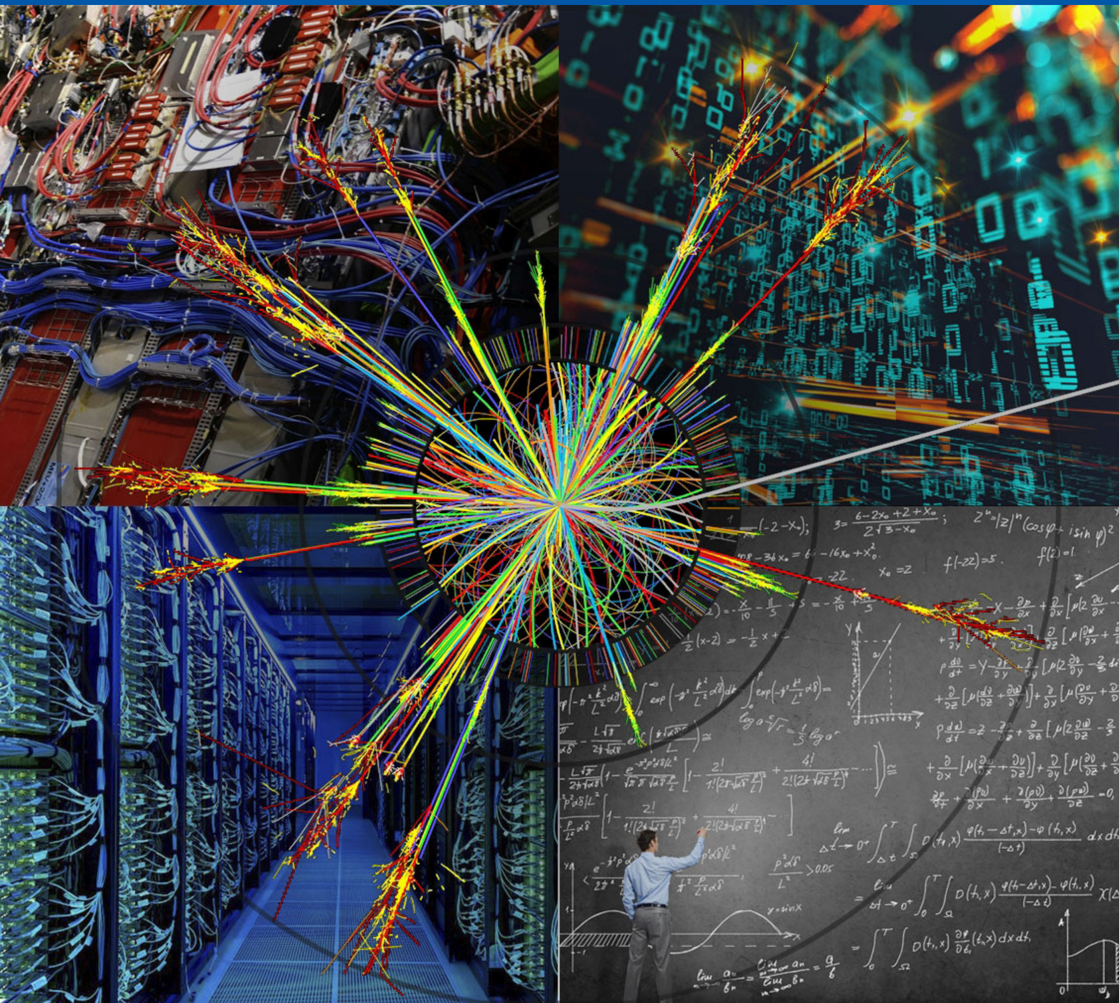
School of Science and Technology
Center for Particle Physics Siegen

UNIVERSITÄT SIEGEN

Master of Science (Physics)

Focus Area: Particle Physics

Description of the Study Program



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Introduction

Particle physics deals with the most fundamental questions related to the structure of matter at smallest distances, pushing the limits of our knowledge to new frontiers. The insights from particle physics also have profound implications on our understanding of cosmology, in particular on the early stages after the Big Bang. In this respect, particle physics is clearly fundamental research, driven by scientific curiosity. Nevertheless, it has a lot of impact on relevant topical challenges we are facing today.

Many results in fundamental physics, which at the time of their discovery had no obvious application, needed a few decades to become part of our daily life. When Heinrich Hertz discovered how to generate electromagnetic waves in 1886, not even he could anticipate the impact that the discovery has nowadays, where wireless communication has become one of the most important pillars of our economic infrastructure. Further examples are the development of quantum mechanics, which started as a purely theoretical activity and decades later became the basis for the semiconductor technology and, eventually, enabled the development of computers. And while the World Wide Web was invented at CERN in the late 1980s as a means of exchanging research-related information, particle physics is nowadays driving the development of future technologies like machine learning in order to process the huge amount of data generated at the Large Hadron Collider (LHC).

Educating young people in such a fundamental science not only lays the seeds for true innovations in the future, but it also shapes scientists with well-trained skills of clear analytic thinking and clever application of scientific methods. It is a remarkable fact that physicists in general and particle physicists in particular have a very broad employability, ranging from science in various disciplines, over the banking, consulting and insurance sectors to management and politics.

The Department of Physics at the University of Siegen has a long tradition in particle physics research, which dates back to its foundation in 1972. After a revision of the curriculum in 2018, the study program **Master of Science (Physics)** allows a focus on **Particle Physics** with specially designed courses to train students in the concepts and methods of modern particle physics. This document introduces the rationale of the course program and describes the details of the curriculum as well as the choices it offers.

Program Objectives

The study program **Master of Science (Physics)** with focus on **Particle Physics** is research oriented, i.e. after its successful completion the students will be qualified to understand and participate in topical research in particle physics. The program is designed for four semesters, and the basis is laid in a two-semester course program consisting of lectures, seminars and a laboratory course, followed by one semester of preparation for research work, which culminates in a master thesis to be prepared during the last semester.

Aside from the scientific specialisation, which qualifies students for an academic or research career, the program aims at providing students with a number of additional skills and competences. Both in experimental and in theoretical particle physics an intensive use of state-of-the-art data technologies, like super computing and machine learning, lies at the heart of the research projects. By being embedded in an international research environment, the students acquire intercultural, teamwork as well as leadership competences. Further soft skills, such as analytic thinking, pragmatic problem solving, presentation skills and efficient use of digital means are among the qualification goals, ensuring an outstanding employability of our graduates.

After completion of the master program, students with outstanding records are encouraged to join a doctoral program. The Department of Physics at the University of Siegen offers a broad range of opportunities to pursue research in particle physics at the doctoral level, and the main research directions of the particle physics groups are listed at the end of this document. The doctoral program builds on the multitude of specialised courses offered in the master program, which facilitates the transition to the doctoral studies and which in turn embeds the master students in a lively and intensive research program, in which they learn early on what research in particle physics consists of.

Requirements

In order to enter the study program **Master of Science (Physics)** with focus on **Particle Physics** a qualified Bachelor degree in Physics is mandatory. In certain cases exceptions from this rule are possible. As a prerequisite a solid foundation of the mathematical methods as well as a good knowledge of the introductory physics courses, such as classical mechanics, electrodynamics, special relativity and, in particular, quantum mechanics is needed. A basic knowledge of elementary concepts in quantum field theory and particle physics is useful, but not required.

Course Program

The study program **Master of Science (Physics)** with focus on **Particle Physics** is structured modularly and comprises a one-year phase of courses followed by a one-year research phase. The workload for individual modules is specified using credit points (CP) according to the European credit transfer and accumulation system (ECTS). For the complete master program the workload amounts to 120 CP, with 1 CP translating into 30 work hours.

The curriculum is subdivided into the following categories:

1. **Mandatory Courses**:
   Laboratory Course and Master Seminar (in total 15 CP)
2. **Mandatory Electives**:
   Two Core Modules and one Elective in the Focus Area (in total 24 CP)
3. **Electives**:
   Further Core Modules and Electives (in total 21 CP)
4. **Research Phase**:
   Preparation Phase, Training Phase and Master Thesis (in total 60 CP)

The course is designed in a way that students can choose a Focus Area in either experimental or theoretical particle physics.

1. Mandatory Courses

The **Laboratory Course** is designed to train practical skills, which can range from experimental work performed in pre-prepared laboratory experiments to project work in theoretical physics. In the Laboratory Course students earn 9 CP, corresponding to 270 work hours. The workload for each project is either 45 or 90 hours, which includes aside from on-site times also the time for preparation and for writing a documentation in form of a report. Students can choose any combination of projects leading to a total workload of 270 hours, e.g. six projects of 45 hours, or three projects of 90 hours. The module is completed and the 9 CP are credited once the students have earned certificates for all the projects that correspond to the 270 work hours.

The Department of Physics currently offers about a dozen Laboratory Course projects, of which the following belong to the Focus Area **Particle Physics**:

Silicon photomultipliers	45 h
Semiconduct. detectors & electronics	90 h
Muon, pion and kaon lifetimes	45 h
Top-quark physics at the LHC	45 h
Monte Carlo tools in particle physics	90 h
Computer-based calculations in QED	90 h
Lattice QCD simulations	90 h

Apart from these, students may choose further projects from other Focus Areas offered by the Department of Physics.

The **Master Seminar** is a seminar series on current topics in particle and astroparticle physics. A key element of the Master Seminar is the combination of experimental and theoretical expertise on particle physics phenomenology, as it is organised jointly by the experimental and theoretical particle physics groups. The goal of the Master Seminar therefore consists in broadening the view on particle physics research beyond what is covered in the lecture program. The students are required to prepare an oral presentation, which is followed by a discussion time, and the evaluation is based both on the presentation skills and the engagement in the discussions during the whole seminar series.

2. Mandatory Electives

The students choose a **Focus Area** in either experimental or theoretical particle physics, which consists of one Core Module (4h lectures + 2h tutorials / week) and one Elective (2h lectures + 2h tutorials / week). After passing the individual modules, they are required to pass an **Oral Exam**, which seeks to put the aquired knowledge in their chosen field of specialisation into a broader context by highlighting the relation between the two modules. In addition, the students are required to attend a second Core Module outside the Focus Area.

The students can choose two **Core Modules** (9 CP each) from the following list:

EPP	Experimental Particle Physics (ST)
CPPP	Concepts and Phenomena in Particle Physics (WT)
TPP1	Theoretical Particle Physics I (ST)
TPP2	Theoretical Particle Physics II (WT)

The distribution of the Core Modules among the two terms allows the students to enter the master program either in the winter term (WT) or in the summer term (ST), as will be illustrated by various exemplary curricula further below. Experimentally-oriented students may choose EPP and CPPP, and theoretically-oriented students TPP1 and TPP2, but any combination of Core Modules is possible.[1] Theoretically-oriented students without a background in quantum field theory should either start with CPPP or TPP1. In addition, students have to choose one Elective (6 CP) as part of their Focus Area from the list of Electives below.

[1] Modules credited as part of a different degree at the University Siegen cannot be credited again as part of the master program and alternative modules need to be selected.

3. Electives

The study program **Master of Sciences (Physics)** with focus on **Particle Physics** offers a broad spectrum of Electives. The current handbook of modules lists the following courses:

ID	Course Title	CP
A1	Data Analysis + Machine Learning	6
A2	Lab Course on Electronics	6
A3	Detector Physics	6
A4	Accelerator Physics II	3
D1	Astroparticle Physics	6
D2	Cosmology	6
D3	Physics at the Pierre Auger Obser.	6
D4	Physics at the LHC	6
E1	Flavour Physics	6
E2	Hadron Physics	6
E3	Collider Physics	6
E4	Higgs Physics	6
F1	Physics beyond the SM	6
F2	Effective Field Theories	6
F3	Calculation of Loop Diagrams	6
F4	Special Topics in QFT	3

In addition, the students may choose other courses offered by the Department of Physics or by other departments of the School of Science and Technology. In the latter case, the students should contact the Examination Office in advance to check if a module can be credited as an Elective for the study program **Master of Science (Physics)**.

Important note:
The study program **Master of Science (Physics)** with focus on **Particle Physics** offers the students a lot of flexibility to choose courses which best match their personal interests. To ensure nevertheless a certain breath, they are required to obtain no less than 9 CP in experimental physics and no less than 9 CP in theoretical physics. They should therefore choose their Core Modules and Electives carefully to make sure that this constraint is satisfied.[2]

4. Research Phase

The research phase consists of three modules, which are designed to encompass a one-year period fully dedicated to a specialised project, culminating in the master thesis. The work in all the three modules takes place within the research groups and is organised according to the individual needs of the project.

The module **Preparation Phase** aims at familiarising the students with necessary tools and methods needed to proceed with the project which will become the master thesis. The 15 CP associated with this module are obtained after a successful evaluation of the required skills by the prospective supervisor.
The Preparation Phase is followed by the module **Training Phase,** which aims at integrating the students into the research work of the group where the master thesis will be conducted. For an experimental project this may include the participation in the set up of an experiment or certain measurements; for a theoretical project this may consist of the development of software tools such as Monte Carlo programs or computer algebra packages to be used in the actual master thesis work. The 15 CP associated with this module are earned once the prospective supervisor of the master thesis testifies the necessary progress of the student.

[2] The Core Module EPP and the Electives from areas A and D are experimental courses, whereas the Core Modules CPPP, TPP1 and TPP2 as well as the Electives from areas E and F are theory courses.

The final module is the **Master Thesis**. In this module the students perform research under supervision, which demonstrates they understand the state-of-the-art in their field of specialisation and which is eventually documented in a thesis. If possible, the thesis should make a small contribution to the topical research in its field. The 30 CP associated with this module are earned once the thesis has been positively evaluated by the supervisor and a second examiner.

Exemplary Curricula

The study program **Master of Science (Physics)** with focus on **Particle Physics** offers the students a lot of flexibility to choose their preferred courses among the Core Modules and Electives as described in the previous sections. In order to illustrate how students with different interests could use this freedom to set up their individually designed curriculum, we list some examples below. To this end, we distinguish between students with a different Focus Area in either experimental or theoretical particle physics, between those who join the master program in the winter term (WT) or summer term (ST), and between those with or without basic knowledge in Quantum Field Theory (QFT) before joining the master program. In the following tables, the number of hours for a lecture is indicated by ”L” and the one for a tutorial by ”T“, and the colours refer to the categories described above:

- Core Modules
- Electives
- Mandatory Courses
- Research Phase

Focus Area: Experimental Particle or Astroparticle Physics (start WT)

Semester 1 (WT)	Semester 2 (ST)	Semester 3 (WT)	Semester 4 (ST)
Astroparticle Physics 2L/2T (6)	EPP 4L/2T (9)	Oral Exam (-)	
CPPP 4L/2T (9)			
Detector Physics 2L/2T (6)	Cosmology 2L/2T (6)		
	Lab Course Electronics 2L/2T (6)		
	Accelerator Physics II 1L/1T (3)		
Laboratory Course (9)	Master Seminar (6)	Preparation + Training (15+15)	Master Thesis (30)

Focus Area: Experimental Particle or Astroparticle Physics (start ST)

Semester 1 (ST)	Semester 2 (WT)	Semester 3 (ST)	Semester 4 (WT)
EPP 4L/2T (9)	Physics at the LHC 2L/2T (6)	Oral Exam (-)	
	CPPP 4L/2T (9)		
Detector Physics 2L/2T (6)	Flavour Physics 2L/2T (6)		
Machine Learning 2L/2T (6)			
Accelerator Physics II 1L/1T (3)			
Master Seminar (6)	Laboratory Course (9)	Preparation + Training (15+15)	Master Thesis (30)

Focus Area: Theoretical Particle Physics (start WT with basic knowledge in QFT)

Semester 1 (WT)	Semester 2 (ST)	Semester 3 (WT)	Semester 4 (ST)
TPP2 4L/2T (9)	Collider Physics 2L/2T (6)	Oral Exam (-)	
	EPP 4L/ 2T (9)		
Higgs Physics 2L/2T (6)	Effective Field Theories 2L/2T (6)		
Tools for Loop Diagrams 2L/2T (6)	Special Topics in QFT 1L/1T (3)		
Laboratory Course (9)	Master Seminar (6)	Preparation + Training (15+15)	Master Thesis (30)

Focus Area: Theoretical Particle Physics (start WT without basic knowledge in QFT)

Semester 1 (WT)	Semester 2 (ST)	Semester 3 (WT)	Semester 4 (ST)
CPPP 4L/2T (9)	Flavour Physics 2L/2T (6)	Oral Exam (-)	
	TPP 1 4L/2T (9)		
Physics at the LHC 2L/2T (6)	Hadron Physics 2L/2T (6)		
Cosmology 2L/2T (6)	Special Topics in QFT 1L/1T (3)		
Laboratory Course (9)	Master Seminar (6)	Preparation + Training (15+15)	Master Thesis (30)

Focus Area: Theoretical Particle Physics (start ST with basic knowledge in QFT)

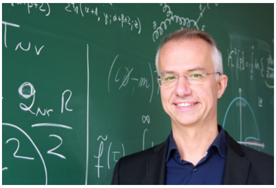
Semester 1 (ST)	Semester 2 (WT)	Semester 3 (ST)	Semester 4 (WT)
Physics beyond the SM 2L/2T (6)	TPP 2 4L/4T (9)	Oral Exam (-)	
EPP 4L/2T (9)			
Astroparticle Physics 2L/2T (6)	Tools for Loop Diagrams 2L/2T (6)		
Special Topics in QFT 1L/1T (3)	Flavour Physics 2L/2T (6)		
Master Seminar (6)	Laboratory Course (9)	Preparation + Training (15+15)	Master Thesis (30)

Focus Area: Theoretical Particle Physics (start ST without basic knowledge in QFT)

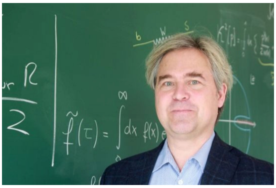
Semester 1 (ST)	Semester 2 (WT)	Semester 3 (ST)	Semester 4 (WT)
TPP 1 4L/2T (9)	Higgs Physics 2L/2T (6)	Oral Exam (-)	
	TPP 2 4L/2T (9)		
EPP 4L/2T (9)	Physics beyond the SM 2L/2T (6)		
Machine Learning 2L/2T (6)			
Master Seminar (6)	Laboratory Course (9)	Preparation + Training (15+15)	Master Thesis (30)

Research Groups

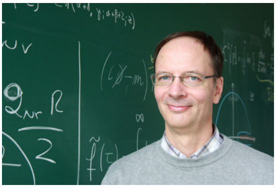
The experimental particle physics groups are currently led by



Prof. Dr. Markus Cristinziani
ATLAS experiment, top-quark physics, pixel detectors, flavour tagging, machine learning

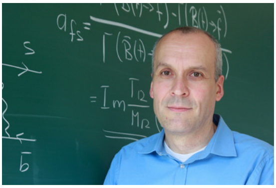


Prof. Dr. Ivor Fleck
ATLAS experiment, top-quark physics, pixel detectors, medical imaging

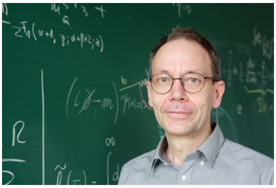


Prof. Dr. Markus Risse
Pierre Auger Observatory, ultra-high energy cosmic rays, data analysis, search for Lorentz violation

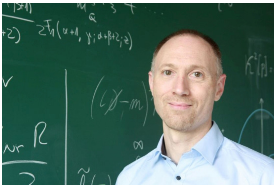
The theoretical particle physics groups include



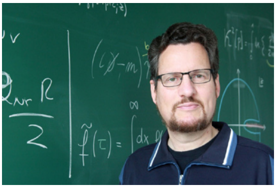
Prof. Dr. Guido Bell
jet physics, flavour physics, precision calculations, soft-collinear effective theory



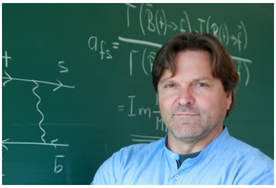
Prof. Dr. Thorsten Feldmann
rare decays of b-hadrons, soft-collinear effective theory, physics beyond the Standard Model



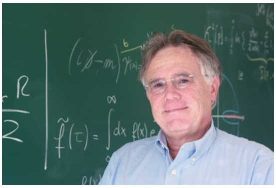
PD Dr. Tobias Huber
flavour physics, precision calculations, effective field theories, algebraic aspects of loop integrals



Prof. Dr. Wolfgang Kilian
electroweak physics, Monte-Carlo event generators, effective field theories



Prof. Dr. Alexander Lenz
mixing and lifetimes of heavy hadrons, QCD sum rules, physics beyond the Standard Model



Prof. Dr. Thomas Mannel
flavour physics, heavy-quark effective theory, QCD sum rules, physics beyond the Standard Model

Contact

For questions concerning the study program **Master of Science (Physics)** with focus on **Particle Physics** please contact the program coordinators:

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More information about the course program and the research pursued by the particle physics groups at the University of Siegen can be found on our webpages.

Experimental Particle Physics:
https://www.hep.physik.uni-siegen.de

Theoretical Particle Physics:
https://www.physik.uni-siegen.de/tp1/

Center for Particle Physics Siegen:
https://www.physik.uni-siegen.de/cpps/

University of Siegen
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