LUND UNIVERSITY

Faculty of Science

FYSC24, Physics: Particle Physics, Cosmology and Accelerators, 7.5 credits

Fysik: Partikelfysik, kosmologi och acceleratorer, 7,5 högskolepoäng

First Cycle / Grundnivå

Details of approval

The syllabus was approved by Study programmes board, Faculty of Science on 2021-03-15 and was last revised on 2024-10-11 by The Education Board of Faculty of Science. The revised syllabus comes into effect 2024-10-11 and is valid from the autumn semester 2025.

General information

The course is a compulsory first cycle course for a degree of Bachelor of Science in Physics and an alternative-compulsory course for a degree of Master of Science in Computational Science with specialisation in Physics.

Language of instruction: English

Main field of study	*Specialisation*
Physics	G2F, First cycle, has at least 60 credits in first-cycle course/s as entry requirements

Learning outcomes

The course intends to give the student an overview over theories and experimental tools that form the basis for our understanding of modern particle physics. The course contains an overview over cosmology and astrophysics to answer unsolved questions concerning the composition of our Universe. The course is also linked to the part of the basic research in the technical development and how tools developed for particle physics are used in society.

Intended learning outcomes in the programme syllabus refer to the programme syllabus of Degree of Bachelor in physics at Lund's university which corresponds to qualitative target for general qualification in the Higher Education Ordinance in turn.

1-8 are milestones towards intended learning outcomes 1 in the programme syllabus

2-8 are milestones towards intended learning outcomes 2 in the programme syllabus

12-13 are milestones towards intended learning outcomes 3 in the programme syllabus

10-13 are milestones towards intended learning outcomes 4 in the programme syllabus

12-13 are milestones towards intended learning outcomes 5 in the programme syllabus

7-8, 14-16 are milestones towards intended learning outcomes 6 in the programme syllabus

7-8, 14-16 are milestones towards intended learning outcomes 7 in the programme syllabus

6-8, 14-16 are milestones towards intended learning outcomes 8 in the programme syllabus

Knowledge and understanding

On completion of the course, the students shall be able to:

1. Describe basic concepts in special relativity theory.

2. Describe the structure of matter in terms of quarks, leptons and force carriers.

3. Describe basic theories and experimental proofs that form the basis for the basic interaction in the standard model (the strong and electroweak forces).

4. Explain the basic elements in Higgs boson theory and its experimental proofs.

5. Explain the reasons that there are predicted phenomena beyond the standard model and give an account of which leading theories that can explain them.

6. Describe how particle physics, cosmology and astrophysics are connected in terms of understanding of the largest unanswered questions in the universe (e.g. dark matter).

7. Describe the most important interactions that are relevant to identify particles and measure their properties, and how this is used in modern particle detectors.

8. Explain the basic principles behind particle accelerators and their use for research and society, particularly those in Lund (MaxIV, ESS) and the Large Hadron Collider.

Competence and skills

On completion of the course, the students shall be able to:

9. Carry out quantitative calculations of reactions and decay with relativistic kinematics and use the method with 4-momentum for quantitative kinematic calculations.

10. Illustrate particle reactions and their decay with Feynman diagrams.

11. Apply conservation laws based on the standard model on reactions and decay.

12. Use an electronic detection system for muons from the cosmic radiation and measure the lifetime of the muons.

13. Carry out a simple data analysis in Python by writing a programme to measure the lifetime of the muon by means of data from experimental measurements and to generalise these lifetime measurements for the time scales for weak decays.

14. Present a report in particle physics where the students have acquired knowledge orally and in writing through working together in groups and divide up the assignments between group members.

Judgement and approach

On completion of the course, the students shall be able to:

15. Discuss why our knowledge of our Universe is incomplete and how we can search for answers through observations and experiments of particles, cosmology and astroparticle physics.

16. Evaluate critically and explain how the tools that are used to answer large questions in particle physics have importance for the society and every day phenomena.

Course content

The course consists of three different themes:

Theme 1: Special relativity

In the first part of the course the students learn about special relativity, its consequences for length and time and about the concept 4-momentum and invariant mass. By means of these theoretical tools, they learn how one calculates two particle decays for relativistic particles.

Theme 2: Theory and experimental methods in modern particle physics

In the other part of the course, the student is given an overview of elementary particles and their interactions. Reactions and decay are represented with Feynman diagrams. The standard model is described in terms of particles and interactions (strong interactions and united electroweak interactions). Finally, the Higgs-mechanism is introduced, and its discovery is discussed in popular terms. Theories beyond the standard model are explained briefly and the lecturers give an introduction to current questions in the research domain of high-energy physics. This part of the course leads to a discussion of professions in science and particle physics with regard to the technical development that is required to answer large questions in the science (for example machine learning, real time analysis, intelligent instrumentation) and their technology transfer.

Theme 3: Particle accelerators and elements in particle detectors and instrumentation

The third component focuses on instrumentation for particle physics. Interactions that are relevant for detection of particles and the methods to identify and measure the momentum of the particles are explained in connection with high energy physics experiments and are connected to other fields of physics. This part includes a laboratory course where the student measures the lifetime for cosmic muons by writing a programme in Python using Jupyter-notebooks.

Since experimental studies of subatomic systems require particle beams with high energy, the principles are described for particle accelerators in a specific part of the course acquired the principles of acceleration, mainly synchrotrons and linear accelerators and storage rings including generation of secondary jets of photons and protons as in MaxIV and ESS. This part of the course highlights the use of particle accelerators for the society in general (e.g. for medical applications and for studies of materials in physics, pharmacology, biology, chemistry). Examples are taken from the forefront of physics, such as the Large Hadron Collider at CERN, and MaxIV and ESS in Lund.

During the whole course, the students refine their transferable proficiencies in programming in the Python-language, since they practise their programming skills during the laboratory session.

The students acquire proficiencies in scientific writing during the preparation of take-home examination by answering open-ended questions about the subjects of the course. They also polish their presentation skills since they in the oral examination must prepare a short presentation about the standard model that is presented by means of whiteboard and slides.

Students can also participate (optionally) in the IPPOG Particle Physics masterclasses, where they develop their proficiencies in science communication for the public with the aim to give students additional possibilities. This is not compulsory.

Course design

The teaching consists of lectures, laboratory sessions, exercises, and a study visit in a large experimental facility. Participation in the introductory lecture, the introduction lecture to the muonlab, as well as laboratory work and following the instructions is compulsory. Participation in the study visit is compulsory but can be replaced by a written project. The study visit can lead to a small cost for the student.

Assessment

Examination takes place in writing in the form of take-home examinations during the course and through an oral examination at the end of the course, and through compulsory components.

Home and oral examinations assess intended learning outcomes 1-9, and the oral examination have a special focus on intended learning outcomes 2-4 and 14-16 since students are requested to describe standard model with their own words and they must be able to answer questions about the application of particle physics in society.

The compulsory components include participation in and passed written lab report for the muonlab that mainly assesses intended learning outcomes 12-13. Participation in the visit at an experimental facility, or or a written report if the facility is also a compulsory part of the course that is not graded.

For students who have not passed the regular examination, additional occasions in close connection to this are offered.

The examiner, in consultation with Disability Support Services, may deviate from the regular form of examination in order to provide a permanently disabled student with a form of examination equivalent to that of a student without a disability.

Grades

Grading scale includes the grades: Fail, Pass, Pass with distinction
To pass the whole course students are requited to have passed examinations approved laboratory report, and participation in all compulsory components (introductory lecture, the introduction lecture to the muonlab, the visit at the experimental facility/written report as compensation).

Take-home examinations and the oral examination correspond to 6 credits. The laboratory report for the muonlab corresponds 1.5 credits.

Grading scale for examinations and laboratory report are Failed, passed, passed with distinction and a percentage grade. Grading scale for study visits/compensation written report is Failed, passed.

Each take-home examination consists of different exercises. The general assessment for take-home examination is the weighted average of the individual exercises including general credits for clarity.

For the oral examination, the students' understanding of the intended learning outcomes and the clarity in the explanations when the student presents the standard model and the clarity in the answers to the teacher's questions are evaluated.

The laboratory report is classified according to the final result (whether the result of the data analysis is compatible with the value of the muon life time) and the clarity of the report. The grade is registered as a separate percentage grade worth 1.5 credits.

The examinations for take-home examinations, oral examinations and laboratory report are marked in percentage points of 100%, that then is converted to the grading scale for the faculty of natural sciences and LTH.

The equivalence between percentage points and grading scale is:

- Failed <50%: (Fail)
- Passed 50% - 79%: (Pass)
- Pass with distinction > = 80% (Pass with distinction)

The total mean for take-home examinations and the oral examination are on an average weighted 25% or 75% of the percentage grade to give the total 6 hp- credits.

The final grade is then calculated as a weighted mean of the percentage grade of the take-home examination and the oral examination (6 credits) and the muonlab (1.5 credits) that are then converted to the grading scale for the faculty of natural sciences and LTH.

Entry requirements

Admission to the course requires general entry requirements, 22.5 credits in physics including knowledge corresponding to:

- FYSB22 Basic Quantum Mechanics, 7.5 credits (at least followed)
- FYSB23 Basic statistical Physics and quantum statistics, 7.5 credits (at least followed), and
- FYSB24 Atomic and Molecular Physics, 7.5 credits (at least followed),

and 45 credits in mathematics (maximum one of the courses incomplete, but at least followed), including knowledge corresponding to:

- MATA21 Analysis in One Variable, 15 credits,
- MATA22 Linear Algebra 1, 7.5 credits,
- NUMA01 Computational Programming with Python, 7.5 credits,
- MATB21 Analysis in Several Variables 1, 7.5 credits and
- MATB22 Linear Algebra 2, 7.5 credits

as well as either 37.5 credits in physics (and if any of the courses FYSB22–24 is completed, a maximum of one of these courses may be incomplete, but at least followed), including knowledge corresponding to:

- FYSA12 Introduction to University Physics, with Mechanics and Electricity, 15 credits

- FYSA13 Introduction to University Physics, with Optics, Waves and Quantum Physics, 7.5 credits
- FYSA14 Introduction to University Physics, with Thermodynamics, Climate and Experimental Methodology, 7.5 credits and
- FYSB21 Mathematical Methods for Vibrations, Waves and Diffusion, 7.5 credits

or an additional 37.5 credits in mathematics (and if all 45 credits of mathematics above are completed, a maximum of one of these courses can be unfinished, but at least followed), including knowledge corresponding to:

- MATB23 Analysis in Several Variables 2, 7.5 credits and
- MATB24 Linear Analysis, 7.5 credits.

Students who have obtained the corresponding knowledge by other means may also be admitted to the course.

Further information

The course is part of the Bachelor's programme in physics, theoretical physics, astrophysics or of the medical physics program. The teaching is based on the assumption that the student follows the program and has assimilated the knowledge in the previous courses, and takes other program courses in parallel. The course is also elective in the Master's programme in computational science. For those who have acquired equivalent knowledge in other ways, the course can be taken as a stand-alone course.

The course may not be counted towards a degree together with FYSC14 Physics: Particle physics, cosmology and accelerators, 7.5 credits or the equivalent earlier courses as well as ÄFYD14, Modern Physics and Physics Education, 30 credits.

The course is cross listed with EXTF85, Particle Physics, Cosmology and Accelerators, 7.5 credits which is given at Lund Faculty of Engineering, LTH.

The examination of the course is scheduled in accordance with the Science faculty exam schedule.

The course is given by the Department of Physics, Lund University.