Maastricht University

PHY3004, 2025

Particle Physics

Course manual

Introduction

This course is an introduction to particle physics, aimed at students with a decent foundation in university physics. It builds on previous knowledge of quantum theory, a bit of relativity, and sometimes some electrodynamics. It is not a course on quantum field theory, those we reserve for the master's level, although we will work with some aspects of it.

In the lectures, an introduction to the world of particles will be given, starting with a historical overview of nuclear physics and particle physics over the last century. We will discuss the fundamental forces of nature, the beautiful underlying symmetries, and learn how read Feynman diagrams for calculating the rates of fundamental processes. The last lecture will be on methods for particle detection in experiments, and modern research topics in high-energy physics.

Course overview

The content of the lectures will be as follows:

Lecture 1: "Particles"	: Particles of matter & types, spin
Lecture 2: "Forces"	: Weak, Strong and EM forces, 4-vectors & diagrams
Lecture 3: "Waves"	: Waves, quantum field theory & gauge invariance.
Lecture 4: "Symmetries"	: Symmetries and the Standard Model Lagrangian
Lecture 5: "Scattering"	: Scattering, cross-sections & perturbation theory
Lecture 6: "Detectors"	: Methods for particle detection. Modern research.

Videos and "flipped classroom" method

In order to follow the lectures, you need to look at each week videos published on canvas **before** the lecture. The videos include the full course material in all gory details. In the lectures we will focus on the main concepts.

For lecture-1: "Particles"
video-1 is Introduction; video-2 and video-3 are nuclear physics; video-4 is particle physics. You may skip video-2 and video-3, which are on nuclear physics, which is not a part of the examination material.

For lecture-2: "Forces"
video-1: electrodynamics and Feynman diagrams
video-2: weak interaction
video-3: strong interaction and some words on relativistic four-vectors

For lecture-3: "Waves"
video-1: quantum wave equations: Schrodinger, Dirac and Maxwell equations
video-2: variational calculus, Lagrangians and Local gauge invariance

For lecture-4: "Symmetries"

video-1: The standard model and Higgs symmetry breaking
video-2: Discrete symmetries: Parity (T), Charge (C) and CP violation

For lecture-5: "Scattering"
video-1: Cross section, decay rate and perturbation theory
video-2: Feynman calculus

For lecture-6: "Detectors" - no video available.

Objectives or Learning Goals

At the end of the course, students will be able to

- Understand the foundations underlying modern particle physics
- Interpret field theory Lagrangians and Feynman diagrams
- Understand the principle of symmetries in nature, and their consequences
- Have a qualitative (and partial quantitative) understanding of which processes may occur in nature, and why
- Be able to give a short lecture on an in-depth particle physics topic (theoretical or experimental)
- Explain what modern high-energy physics is about, and which problems it faces.

Course Coordinator and tutors

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Schedule: Tutorials & Homework

The course lasts seven weeks. In weeks 1-5 there is a lecture and two tutorials. On the Monday tutorial you will hold discussions in the Thursday one you will work on exercises. In the sixth week, there will be oral (and peer-reviewed) 10-minute presentations during one of the tutorials, to be announced. This presentation serves as “mid-term”. In the seventh week the Exam will take place.

<u>Weekly Exercises week 1-5:</u>
On Thursdays we will make and discuss the homework exercises of last week in a group form. These will consist of some superficial questions regarding basic understanding of the content of the lecture, and some questions that will require you to self-educate, with the knowledge from the lecture in hand. The weekly exercises will be handed in to your tutor (Evridiki or Xenofon) by Monday by submission on Canvas. Please start working on them after the lectures so that you can get hints for any problems or ask for specific explanations during the Thursday tutorials.

<u>Weekly discussions during Monday Tutorial:</u>
The discussion sessions will be led by pre-appointed students on specific topics that are important in preparation of next week’s lecture, which will require some study beforehand. You will all be assigned three times in small groups to prepare an introduction of a topical subject for the Monday tutorial. When you are assigned a topic (see below which topic and look it up on Canvas in the corresponding module), you should prepare it to lead a discussion of about 15-20 minutes on the subject with the tutor group. You are expected to introduce the topic, perhaps prepare a few slides or write on the board, and be somewhat of an expert. At the same time you do not have to know everything. You may also address questions to the tutor group. Your contribution will be evaluated in terms of effort.

<u>“Research” presentation in week 6:</u>
During the course, you are required to pick a topic of interest (suggestions below are provided), and prepare a short presentation on it, in teams of 2. In the sixth week, we will organize a small colloquium where everyone will give a short (10 min.) presentation on your research. These presentations will be peer-reviewed and are also part of the assessment.

<u>Final Exam in week 7:</u>
In the final week, there will be a written exam.
The Thursday tutorial session in week 6 will serve as “recap” of the course and will give you the possibility to ask further questions in preparation of the exam.

Discussion schedule:

#	*Tutor Group*	*Name*	*Discussion Topics*	*Week nr*
1	1	Defne Adas	1 & 7 & 13	w1 & w3 & w5
2	1	Kristof Pipal	1 & 8 & 14	w1 & w3 & w5
3	1	Guus Beenen	2 & 9 & 15	w1 & w3 & w5
4	1	Luna Hoenders	2 & 7 & 13	w1 & w3 & w5
5	1	Jakub Gorzelany	3 & 8 & 14	w1 & w3 & w5
6	1	Phil Notych	3 & 9 & 15	w1 & w3 & w5
7	1	Francesco Cipollone	4 & 10 & 13	w2 & w3 & w5
8	1	Morgan Jools van Steen	4 & 11 & 14	w2 & w3 & w5
9	1	Ediz Yakupoglu	5 & 12 & 15	w2 & w4 & w5
10	1	José Hemink	5 & 10 & 13	w2 & w4 & w5
11	1	Inaki Pardo Zambrana	6 & 11 & 14	w2 & w4 & w5
12	1	Livia Pantiglioni	6 & 12 & 15	w2 & w4 & w5
13	2	Panagiotis Melas	1 & 7 & 13	w1 & w3 & w5
14	2	Cristina Moisuc	1 & 8 & 14	w1 & w3 & w5
15	2	Phu Lam Trinh	2 & 9 & 15	w1 & w3 & w5
16	2	Clotilde Papot	2 & 7 & 13	w1 & w3 & w5
17	2	Jude Bethinger Busquet	3 & 8 & 14	w1 & w3 & w5
18	2	Sophia Berinski	3 & 9 & 15	w1 & w3 & w5
19	2	Magda Jagielska	4 & 10 & 13	w2 & w4 & w5
20	2	Daniel Gruber	4 & 11 & 14	w2 & w4 & w5
21	2	Lara Kropej	5 & 12 & 15	w2 & w4 & w5
22	2	Laura Jo Lykles	5 & 10 & 13	w2 & w4 & w5
23	2	Ellis Knowles	6 & 11 & 14	w2 & w4 & w5
24	2	Aleksandre Kiria	6 & 12 & 15	w2 & w4 & w5

Assessment of the Course

The evaluation of the course contains four elements:
1) **50%**: Written examination: score in the range 0 – 10
2) **20%**: Handing in of weekly homework exercises to your tutors:
   score: nothing (0), insufficient (4), sufficient (7), good (10)
3) **15%**: Presentation of a research project at the last week of the course: score: 0 – 10.
4) **15%**: Participation in the discussion sessions during Monday tutorial:
   score: nothing (0), insufficient (4), sufficient (7), good (10)

Attendance and resit policy

This course has an 85% attendance requirement. This means you have to be present at at least 8/10 tutorial sessions. You are recorded as 'not present' if you are more than 5 minutes late. If you fail to meet these requirements, you will be eligible for an additional assignment, according to the MSP rules and regulations. The lectures are not mandatory, but presence is strongly recommended and will be recorded.

You are eligible for an additional assignment if

- There is a valid reason and proof for *all* your absences
- You have directly informed the course coordinator of your absences on the same day of the absence (by email).

You may apply for a resit if your final grade is below 5.5. In order to be eligible, you

- Meet the attendance requirement of the course
- Made a fair attempt at fulfilling all course requirements. 'Fair' is to be judged by the course coordinator.

Material

The base course material is taken from Griffiths - Introduction to elementary particles (second revised edition). Further material on particles & QFT (with relatively little math) can be found in Aitchison & Hey, 'Gauge theories in particle physics', and Halzen & Martin, 'Quarks & Leptons'. Interested students could have a look at the Feynman lectures on physics.
Furthermore, there exists a series of lecture notes that go more in-depth on various topics discussed in this course. Links to those are
https://www.nikhef.nl/~i93/RQW/2017/Lecture.pdf
https://www.nikhef.nl/~i93/Master/PP1/2017/Lectures/Lecture2017.pdf
https://www.nikhef.nl/~h71/Lectures/2015/ppII-cpviolation-29012015.pdf

On the project and presentation

Since there is so much to see and learn in the world of particle physics, and only 6 weeks to show you some aspects of that, we want you to dive into a subject of your own liking and do some research about it. You will present that research to the other students in a 10 min. presentation. You may group up with another student. The subject should connect to the content of the course, and should be proposed to the course coordinator before starting.

Many potential subjects will be highlighted during the lectures, such as
- neutrino oscillations
- supersymmetry
- modern challenges in sustainable fusion
- leptoquarks or other extensions to the SM

- the matter-antimatter puzzle and CP violation
- searching for dark matter
- particle detector optimisation
- modelling the strong nuclear force
- renormalisation (quite QFT theoretical)
- stability of the proton
- the anomalous magnetic moment of the muon

Grading rubrics the lecture, will be given in due time.