# COURSE DATA

| Data Subject | |
|---|---|
| **Code** | 43295 |
| **Name** | Strong interactions |
| **Cycle** | Master's degree |
| **ECTS Credits** | 6.0 |
| **Academic year** | 2022 - 2023 |

**Study (s)**

| Degree | Center | Acad. year | Period |
|---|---|---|---|
| 2150 - M.D. in Advanced Physics | Faculty of Physics | 1 | First term |

**Subject-matter**

| Degree | Subject-matter | Character |
|---|---|---|
| 2150 - M.D. in Advanced Physics | 2 - Fundamental interactions | Optional |

**Coordination**

| Name | Department |
|---|---|
| PAPAVASSILIOU, JOANNIS | 185 - Theoretical Physics |

# SUMMARY

In the course “**Strong interactions”** the student will learn a plethora of basic concepts and techniques about Quantum Chromodynamics (QCD). We will study the symmetries of the QCD Lagrangian, its covariant path integral quantization, and will derive the Feynman rules describing the interaction between gluons, quarks, and ghosts. One-loop results will be computed in detail, and the concepts associated with renormalization and the asymptotic freedom will be introduced. A brief introduction to non-perturbative techniques will be presented.

# PREVIOUS KNOWLEDGE

### Relationship to other subjects of the same degree

There are no specified enrollment restrictions with other subjects of the curriculum.

### Other requirements

Quantum Field Theory

## OUTCOMES

### 2150 - M.D. in Advanced Physics

- Students can apply the knowledge acquired and their ability to solve problems in new or unfamiliar environments within broader (or multidisciplinary) contexts related to their field of study.
- Students are able to integrate knowledge and handle the complexity of formulating judgments based on information that, while being incomplete or limited, includes reflection on social and ethical responsibilities linked to the application of their knowledge and judgments.
- Students can communicate their conclusions, and the knowledge and rationale underpinning these, to specialist and non-specialist audiences, clearly and unambiguously.
- Students have the learning skills that will allow them to continue studying in a way that will be largely self-directed or autonomous.
- Students have the knowledge and understanding that provide a basis or an opportunity for originality in developing and/or applying ideas, often within a research context.
- Ser capaz de gestionar información de distintas fuentes bibliográficas especializadas utilizando principalmente bases de datos y publicaciones internacionales en lengua inglesa.
- Saber organizarse para planificar y desarrollar el trabajo dentro de un equipo con eficacia y eficiencia.
- Ostentar la preparación para tomar decisiones correctas en la elección de tareas y en su ordenación temporal en su labor investigadora y/o profesional.
- Poseer la capacidad para el desarrollo de una aptitud crítica ante el aprendizaje que le lleve a plantearse nuevos problemas desde perspectivas no convencionales.
- Estar en disposición para seguir los estudios de doctorado y la realización de un proyecto de tesis doctoral.
- Comprender de una forma sistemática el campo de estudio de la Física y el dominio de las habilidades y métodos de investigación relacionados con dicho campo.

- Concebir, diseñar, poner en práctica y adoptar un proceso sustancial de investigación con seriedad académica.
- Realizar un análisis crítico, evaluación y síntesis de ideas nuevas y complejas en el área de la Física.
- Analizar una situación compleja extrayendo cuales son las cantidades físicas relevantes y ser capaz de reducirla a un modelo parametrizado.
- Evaluar la validez de un modelo o teoría propuesto por otros miembros de la comunidad científica.
- Saber modelizar matemáticamente los problemas físicos sencillos nuevos, conectados con problemas conocidos. Ser capaz de expresar en términos matemáticos nuevas ideas.
- Elaborar una memoria clara y concisa de los resultados de su trabajo y de las conclusiones obtenidas en el área de la Física.
- Exponer y defender públicamente el desarrollo, resultados y conclusiones de su trabajo en el área de la Física.
- Saber construir modelos de acuerdo con el contenido en partículas y en simetrías de la teoría. Analizar y comprender los límites de validez de las teorías físicas.
- Conocer y saber utilizar la invariancia de gauge local como punto de partida en la formulación de las interacciones fundamentales.
- Comprensión de las propiedades fundamentales de la interacción fuerte (confinamiento, libertad asintótica y simetría quiral) y su relación con la distancia.

## LEARNING OUTCOMES

At the end of the teaching-learning process the student will have learned to:

1. Select and correctly use various sources of information in both traditional and electronic format. Know the basics of file own field: inspire, spiers, arXiv.
2. Properly handle and interpret qualitative and quantitative physical data which validate the known theories in the field.
3. Analyze information from physical systems.
4. Prepare documents and reports in a text written in an understandable way organized, documented and illustrated.
5. Articulate oral discourse, structured, consistent, with good diction and use of technical vocabulary.
6. Understand the arguments used in the field of theoretical physics.
7. Understanding the mathematical description of physical processes of particle creation and destruction. Understanding the formalism of quantum field theory in the mathematical description of physical models.
8. Use the basic concept of a constituent of matter. Knowing the phenomenology of elementary particles. Know how to classify the elementary particles and fundamental interactions.
9. Describe the processes of collision and disintegration of particles at the tree. Being able to develop and use the techniques of approximation in the calculation of particle interactions. Being

able to predict physical quantities (cross sections, lifetimes, ...) of particles from a given theory.

10. Understand the concept of particle-mediated interaction and the methodology of quantum field theory.

## DESCRIPTION OF CONTENTS

### 1. Quarks and colour

The quark model. Colour. Jets. Confinement.
Asymptotic freedom.

### 2. The QCD Lagrangian

Gauge symmetry. QED. SU(N) gauge theory.
Gluons. Global symmetries

### 3. Covariant quantization-Faddeev-Popov construction

Introduction to path integral quantization. Gauge fixing and ghosts.
Feynman rules of QCD.

### 4. One-loop calculations

Dimensional regularization and Feynman parametrization.
Self-energies of gluon, ghost, quark.

### 5. Renormalization of QCD

Classification of divergences. Superficially
divergent diagrams. Renormalization

### 6. Renormalization group

Effective running coupling. Asymptotic
freedom. Anomalous dimensions. Quark masses.

### 7. BRST symmetry

BRST symmetry. Derivation of Slavnov-Taylor identities.
Comparison with Ward-Takahashi identities.

### 8. Optical theorem and ghosts

The optical theorem in general.
The case of gluons as external states and the role of the ghosts

### 9. Nonperturbative aspects

Lattice formulation of gauge theories.
Introduction to Schwinger-Dyson equations.

## WORKLOAD

| ACTIVITY | Hours | % To be attended |
|---|---|---|
| Theory classes | 40,00 | 100 |
| Seminars | 3,00 | 100 |
| Other activities | 3,00 | 100 |
| Development of group work | 10,00 | 0 |
| Development of individual work | 11,00 | 0 |
| Preparing lectures | 43,00 | 0 |
| Preparation of practical classes and problem | 40,00 | 0 |
| **TOTAL** | **150,00** | |

## TEACHING METHODOLOGY

MD1 - Standar theory lecture

MD2 - Discussion of articles (readings).

MD3 - Problem solving

MD4 - Problems

MD8 - Conference of experts

# EVALUATION

SE1 - Written exam on the theory and practical lectures: based on the results of learning and the specific objectives of each subject (50%).

SE5 - Evaluation of non-presential activities related to theory and practical lectures: Problem sets submitted (50%).

# REFERENCES

## Basic

- P. Pascual y R. Tarrach, QCD: Renormalization for the Practitioner, Springer-Verlag, 1984.
- F. J. Yndurain, The theory of Quark and Gluon Interactions, 4Ed, Springer-Verlag, 2006, ISBN 354033209X.
- T. Muta, Foundations of Quantum Cromodynamics, World Scientific, 1987